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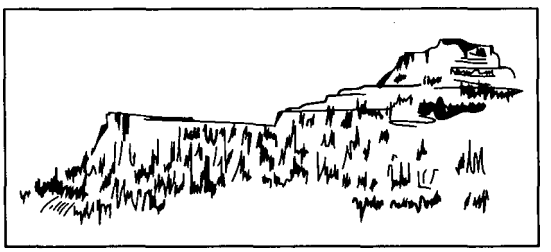
Conference on **Technology-Based Confidence Building:** Energy and Environment

sponsored by the
University of California

hosted by
Los Alamos National Laboratory :
Center for National Security Studies
Earth and Space Sciences Division

July 9-14, 1989
St. John's College
Santa Fe, New Mexico

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CNSS
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The Center for National Security Studies is a studies and analysis organization of the Los Alamos National Laboratory. Drawing on the broad knowledge at Los Alamos of science and engineering relevant to national security issues, the Center's research focuses on the interaction between technology and policy and on developing insights that may improve the relationship between the development of new technology and the achievement of national policy goals. The Center's staff includes both resident and visiting researchers.

The principal mission of the Center is to promote and conduct long-term research and analysis in the broad areas of arms control, national defense, low-intensity conflict and terrorism, energy security, and technological competitiveness. In addition, it provides insight about national security policy, strategy, and technology issues to the Laboratory staff, thus helping Los Alamos better address national needs. Finally, the Center serves as a focus for the exchange of ideas on international security issues for Los Alamos.

The Center documents its work in a number of publications. The ***Briefs*** are short informal papers commenting on topics which are appropriate to the Center's areas of interest. The ***CNSS Papers*** are more extensive documents which may be monographs, seminar talks, or workshop proceedings. The ***Reports*** are formal research papers or edited conference proceedings on topics appropriate for Center sponsorship. A book series, ***Issues in National Security***, will report the results of the Center's research on key national and international security issues.

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CONFERENCE ON
TECHNOLOGY-BASED
CONFIDENCE BUILDING:
Energy and Environment

Sponsored by
University of California

Hosted by
Los Alamos National Laboratory:
Center for National Security Studies
Earth & Space Sciences Division

Sunday July 9, 1989

Registration after 12:00 P.M. at St. John's College Conference Center, Peterson Center Lobby

6:00 P.M. - Reception by the Organizing Committee in the Junior Commons Room

Monday July 11, 1989 (Great Hall)

8:30 A.M. - 9:00 A.M. - Chairman, Louis Rosen, LANL

WELCOME - Sig Hecker, Director of Los Alamos National Laboratory

OPENING REMARKS - Paul White, Acting Director, Center for National Security Studies, LANL

MESSAGE from Senator Pete Domenici, New Mexico

9:00 A.M. - 12:30 P.M. PLENARY SESSION II.

Science, Technology and Confidence Building: Review of Cooperative Activities

Chairman, Paul Brown, Lawrence Livermore National Laboratory

ADDRESS by Congressman George E. Brown, Jr, California

-"Magnetic Fusion - An Example of International Cooperation" T. Kenneth Fowler - Chairman, Dept. of Nuclear Engineering, UCB

-"U.S.-Soviet Exchanges in Confidence-Building" Glenn Schweitzer - National Academy of Science

-"International Cooperation in Magnetic Fusion Energy: Scope & Issues Harry Dreicer, Div. Ldr., Controlled Thermonuclear Research, LANL

-"Environmental Concerns of the United States" Harlan Watson, Department of the Interior (for Secretary Manuel Lujan)

-"East-West Technology Cooperation as a Means for Overcoming Division in Europe" Peter Schulze - Friedrich Ebert Foundation, London, England

12:30 P.M.-2:00 P.M. LUNCH Main Dining Hall

2:00 P.M. - 5:30 P.M. PLENARY SESSION II.

Overview of Issues Where International Cooperation is Essential

Chairwoman: Ann Florini, Center for International Strategic Affairs, UCLA

-"Energy: The Coin of International Understanding." Alex Zucker, Associate Director, Nuclear & Engineering Technologies, ORNL

-"Coordination of National Energy Policies" Alan Sweedler, Director, Center for Energy Studies, SDSU

-"Energy Security in a Competitve World" Mike Stevenson, Deputy Associate Director, Energy & Technology, LANL

-"Future of Solar Energy & Summary of Conference in France" H.M. Hubbard, Director, Solar Energy Research Institute

-"Report on June Meeting of the Club of Rome" Ivo Šlaus - Ruder Bošković Institute, Zagreb, Yugoslavia

-"The Links Between Politics & Technology in the Implementation of Technology-Based Confidence Building" Gerald Steinberg, Dept. of Political Science, Bar-Ilan University, Israel

-"Relevance of International Research Facilities to International Stability" (Contributed Paper) Louis Rosen, Senior Fellow, LANL

5:45-7:15 DINNER Main Dining Hall

7:30 P.M. - 10:00 P.M. PLENARY SESSION IIA.

Chairman: John Whetten, Associate Director, Energy & Technology, LANL

-"The Challenges & Limitations of Mathematical Modeling of Environmental Issues" Gottfried Mayer-Kress, Santa Fe Institute/Center for Nonlinear Studies (CNLS), and David Campbell, Director, CNLS, LANL

-"Nuclear Power in the Context of Global Warming" David Bodansky, Department of Physics, University of Washington

-"The Next Generation of Nuclear Reactors" Alvin Weinberg, President, Institute for Energy Analysis, Oak Ridge Associates

-"History of Pacific Basin Consortium" Harvey Drucker, Argonne National Laboratory

Tuesday July 11 (Great Hall)

8:30 A.M. - 12:30 P.M. PLENARY SESSION III.

Mechanisms for Cooperation

Chairwoman: Martha Krebs, Lawrence Berkeley Laboratory

-"The Internationalization of Nuclear Safety" Morris Rosen, Director of Nuclear Safety, IAEA

-"U.S.-U.S.S.R. Collaboration in High Energy Physics" Roy Rubinstein, Assistant Director, Fermi National Accelerator Laboratory

-"Overview of Collaboration of Soviet-American Gallium Experiment" Gerry Garvey, Director of LAMPF, LANL

-"Los Alamos-U.C. Joint Activities in Global Change" Chic Keller, Center Director, Institute for Geophysics & Planetary Physics, LANL

-"International Cooperation on Energy Efficiency Technology Development" Martha Krebs, Lawrence Berkeley Laboratory

-"International Cooperation on Environmentally Acceptable Technologies" Oleg Favorsky, USSR

12:30 P.M. - 2:00 P.M. LUNCH Main Dining Hall

2:00 P.M. - 4:00 P.M. Walking Tour of Santa Fe, Kay Harper

(For sturdy adventurers only)

- Free Time

- Vans will take people into Santa Fe at 2:00 P.M. and pickup at La Fonda at 5:30 P.M. and 9:00 P.M.

6:00 P.M. - 7:30 P.M. DINNER Main Dining Hall

Wednesday, July 12 (Great Hall)

8:30 A.M. - 12:30 P.M. Parallel Session: WORKSHOP I.

Environmental Challenges

Chairman: Will Kellogg, National Center for Atmospheric Reseach

-"Global Change" Thomas Malone, Scholar-in-Residence, St. Joseph College

-"The Ocean's Role in the Climate" Robert Chervin, National Center for Atmospheric Research

-"Environmental Collaborations in the Use of Accelerator Mass Spectrometry" Jay C. Davis, Center for Accelerator Mass Spectrometry, LLNL

-"Joint Cooperation Activities in Agriculture" Anne Ehrlich, Department of Biological Sciences, Stanford University

-"Historic Analysis of Extreme Natural Phenomena and their Relationship with Scientific, Technical, and Social Progress" E.P. Borisenkov, Director, Main Geophysical Observatory, Leningrad

-"Difficulties in Understanding and Solving Global and Environmental Problems By Specialized Scientific Expertise" Sylvius Hartwig, Bergische Universität-GH-Wuppertal, FRG

-"Economic and Political Implications of Climate Change" Will Kellogg, National Center for Atmospheric Research (ret)

-"Politics of International Cooperation" Peter Haas, University of Massachusetts

12:30 P.M. - 2:00 P.M. LUNCH Main Dining Hall

2:15 P. M. - 5:30 P.M. WORKSHOP I, continued:

-"Confidence Building in the Third World Challenge" Ronnie Lipschutz, Pacific Institute for Studies in Development, Environment, and Security

-"The Multiple Domains of the Climate Change Problem: A Los Alamos Perspective" Sumner Barr & Paul Mutschlecner, Earth & Space Sciences, LANL

-"International Scientific Cooperation in the Arctic: Inherent Difficulties & Potential Rewards" Juan Roederer, Geophysical Institute, University of Alaska

-"Antarctic Research: Importance for Global Climate Change" Ruth Reck, General Motors Laboratory

-"Opportunities for US-USSR Cooperation in the Investigation of the Arctic Stratospheric Ozone" W.R. Sheldon, Department of Physics, Univesity of Houston

-"Challenges in Predicting Environmental Quality" Julius Chang, State University of New York at Albany

-"Air Quality Studies in the Western United States" Ted Yamada, Earth & Space Sciences, LANL

-"International Means for Cooperation on Environmental Issues" Tatiana Kazakova, Ministry of Foreign Affairs, USSR

Wednesday, July 12 (Junior Commons Room)

8:30 A.M. - 12:30 P.M. Parallel Session, WORKSHOP II.

Fission Energy

Chairman: Ron Augustson, Safeguards Assay Group, LANL

-"A Cleaner Environment with Nuclear Heating" Jerry Cuttler, Whiteshell Nuclear Research Establishment, Canada

-"Nuclear Energy and the Environment" Wang De Li, Institute of Applied Physics & Computational Mathematics, and Zhou Yunhua, Committee on Science, Technology, & Industry for National Defense, PRC

-"An International Agenda for Enhanced Nuclear Safety & Performance" Kent Hansen, MIT

-"Nuclear Power and East-West European Cooperation" Cesare Silvi, Italian Commission for Nuclear Safety & Performance

-"Designing Effective Protection Against Threats at Nuclear Facilities" Garth Cummings, LLNL,

-"U.S.-U.S.S.R Collaboration on Inherently Safe Nuclear Reactors" Jack Barkenbus, Deputy Director, Energy, Environment & Resource Center, University of Tennessee

-"Joint U.S.-U.S.S.R. Cooperation on High-Level Waste Management" Paula Burgett, BDM Corporation, & Stephen Schoderbek, National Security Analysis Consultant

-"Nuclear Winter Threat" Alexander Ginzberg, Institute for Atmospheric Physics, USSR

12:30 P.M. - 2:00 P.M. LUNCH Main Dining Hall

2:15 P.M. - 5:30 P.M. WORKSHOP II, continued

-"Safety Aspects of Evolutionary & Advanced Reactors" Eric Beckjord, U.S. Nuclear Regulatory Commission

-"Nuclear Waste and Need for International Solutions" Luther Carter, Independent Writer, Washington, DC

-"Confidence Building in and through Fission and Fusion Activities" Toyojiro Fuketa, Vice President, Japan Atomic Energy Research Inst.

-"Geologic Containment of Radioactive Waste" Don Barr, Division Leader, Isotope & Nuclear Chemistry Division, LANL

-"Nuclear Energy, Coal & Environment" Yang Yin, China Institute for Radiation Protection, PRC

-"Role of IAEA Safeguards in Confidence Building" Ron Augustson, Safeguards Assay Group, LANL

6:00 P.M. - 7:30 P.M. DINNER Main Dining Hall

Wednesday, July 12 (Senior Commons Room)

8:30 A.M. - 12:30 P.M. Parallel Session, WORKSHOP III.

Conservation, Fossil Fuels & Renewables

Chairman: Robert Schock, Energy Program, LLNL

-"Decline of Energy Use in the 70's & Early 80's" Iris Borg, Energy Program, LLNL

-"The Greening of Superpower Relations: Cooperative Ventures in Environmental Protection and Conservation of Resources" David McClave, Federal Research Division, Library of Congress

-"Inter-Academy Collaboration on Energy Conservation Research & Development" Robert Socolow, Center for Energy & Environment, Princeton University

-"Environmental Perestroika: Energy Technology & East-West Confidence Building" Joel Swisher, Department of Engineering, Stanford University

-"A Perspective on the Impact of New Technologies on Petroleum Recoveries" Francis Finch, Director's Office, LANL & Robert Hanold, Earth & Space Sciences, LANL

-"Energy Technology R & D: What Could Make a Difference?" David Reister, ORNL

-"International Solar-Terrestrial Physics Program (ISTP)" Ted Fritz, Earth & Space Sciences, LANL

12:30 P.M. - 2:00 P.M. LUNCH Main Dining Hall

2:15 P.M. - 5:30 P.M. WORKSHOP III, continued

-"Global Housekeeping with Conventional Energy" Mike Berger, Office Director for Energy & Technology Initiatives, LANL

-"Geothermal Energy: An International, Secure, Useful Resource" Bob Greider, Geothermal Resources International, Inc.

-"Central American Cooperation" N. Anne Tellier, Program Manager for International Programs, LANL

-"Macro-Engineering Projects for Technology" Harris Mayer - LANL Consultant

-"International Cooperation on Environmentally Compatible Technologies" Yuri Alexander Chernegov, Chairman of Program Technology of the 21st Century of the Foundations for Social Inventions, USSR

6:00 P.M. - 7:30 P.M. DINNER Main Dining Hall

Wednesday, July 12 (Galleria Room)

8:30 A.M. -12:30 P.M. Parallel Session, WORKSHOP IV.

Disaster Response

Chairman: Jim Makris, U.S. Environmental Protection Agency

-"Preparedness for and Prevention of Chemical Accidents: Past, Present & Future" Jim Makris, U.S. Environmental Protection Agency

-"International Disaster Relief: Obstacle to Immediate Response" Enso V. Bighinatti, Under Secretary General (ret.), League of Red Cross & Red Crescent Societies, Geneva

-"International Co-operation in Planning and Preparing for Nuclear Accidents or Radiological Emergencies" Ephraim Asculai, IAEA, Austria

-"Opportunities for Cooperation in Nuclear Accident Preparedness & Management: Procedural & Organizational Measures" John Lathrop, Strategic Insights

12:30 P. M- 2:00 P.M. LUNCH Main Dining Hall

2:15 P.M. - 5:30 P.M. WORKSHOP IV, continued

-"A Desktop-Computer Forecast for Emergency Response Planning" Ted Yamada, Earth & Space Sciences, LANL

-"Real-Time Global Mutual Aid for Atmospheric Releases of Radioactivity is Possible Today" Thomas Sullivan, ARAC, LLNL

-"Accidental Release of Hazardous Materials in the Atmosphere" Ron Koopman, LLNL

-"Aids Modeling" Mac Hyman, Mathematical Modeling & Analysis Group, LANL

-"Uses of Mathematical Models in the Aids Epidemic" Ann Stanley, Mathematical Modeling and Analysis, LANL

-"Mathematical Modeling of Weather" Gottfried Mayer-Kress, Center for Nonlinear Studies, LANL

6:00 P.M. - 7:30 P.M. DINNER Main Dining Hall

Thursday, July 13 (Great Hall)

8:30 A.M. - 12:30 P.M. Parallel Session, WORKSHOP I, continued

Chairman: Will Kellogg, NCAR

-"Mission to Planet Earth" John McLucas, U.S. International Space Year Association

-"Space Solar Power" Mel Eisenstadt and Jay Sorenson, Dept. of Political Science, UNM

-"Rethinking the Open Skies in the Information Age" Robert Katula, Congressman Robert Mrazek's Office

-"Understanding Global Change - The International Geosphere-Biosphere Programme" Ruth Reck, General Motors Research Laboratory

-"Politics of International Cooperation" Peter Haas, University of Massachusetts

-"Commercial Satellites and Their Impact on National Security" Dean Michael Nacht, School of Public Affairs, University of Maryland

2:30 P.M. - 5:30 P.M.

DISCUSSION

Thursday, July 13 (Junior Commons Room)

9:30 A.M. - 5:30 P.M. Parallel Session, WORKSHOP II, continued

Chairman: Ron Augustson, Earth & Space Sciences Division, LANL

Selected Research Activities on Fission Energy and the Environment in the USSR, Oleg Favorskiy, Alexander Ginsberg, and Tatiana Kozikova

DISCUSSION

Thursday, July 13 (Senior Commons Room)

9:30 A.M. - 5:30 P.M. Parallel Session, WORKSHOP III, continued

Chairman Bob Schock, Energy Program, LLNL

DISCUSSION

Thursday, July 13 (Galleria)

9:30 A.M. - 5:30 P.M. Parallel Session, WORKSHOP IV, continued

Chairman: Jim Makris, U.S. Environmental Protection Agency

DISCUSSION

12:30 P.M. - 1:30 P.M. LUNCH Main Dining Hall

6:00 P.M. - 9:00 P.M. BARBEQUE Main Patio

Friday, July 14 (Great Hall)

PLENARY SESSION IV.

8:15 A.M. - 8:35 A.M. - "A Journalist's Perspective: Lessons of the Joint Verification Experiment" Lawrence Spohn, Albuquerque Tribune

8:35 A.M. - Reports of Chairpersons

Chairman: Doyle Evans, Earth & Space Sciences Program Manager, LANL

-Summary Address, Serguei P. Kapitza, USSR Institute for Physical Problems, Moscow

- Closing Remarks by Louis Rosen

11:30 A.M. - 1:30 P.M. - FAREWELL LUNCHEON Main Dining Hall

FROM THE EDITORS

The major aim of the editors has been publication of this volume in three months, or as little time beyond three months as we could manage. This extraordinarily short publication time made us choose compromises and methods that a more leisurely schedule would have avoided, and we want our authors to understand some of the constraints we were forced to recognize.

Design and format were chosen as that of the Center for National Security Studies of Los Alamos National Laboratory, which sponsored the publication.

Editing was done mostly, though not always, to the standard of *Los Alamos Science*, the flagship publication of Los Alamos National Laboratory. It was not possible to achieve uniformity of style in all papers with such a short publication schedule. What we sought, rather, was consistency in style within a paper. Doubtless we did not achieve this goal in every case, but we tried.

We have produced this large volume in what may be a record time. In the process we have made queries to many authors, all of whom responded cordially and quickly. In a few cases we have altered or deleted figures and rewritten text to reflect these changes, where we could not make suitable reproductions of the figures.

In a volume of this size, given its short publication schedule, there are bound to be omissions and errors. If there are serious errors, authors should advise us and Errata will be issued.

Reading the papers and working with the authors was a rewarding experience. These are important Proceedings and the editors send their compliments and thanks to the authors.

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FOREWORD & ACKNOWLEDGEMENTS

by

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About one year ago it was suggested to the University of California that the time had come to convene a rather unusual international conference. The unusual nature of the conference stemmed from its very ambitious goals as well as its focus on a highly diverse group of outstanding researchers who are dedicated to addressing major global problems while improving the international climate for progress towards a more peaceful world.

The University of California invited a short formal proposal which was duly prepared and followed by the creation of an organizing committee that henceforth decided on the direction and agenda and invitees for the Conference.

It is appropriate that we acknowledge the interest and good wishes of Dr. James S. Kane, Special Assistant to the President of the University of California. We do so by quoting from his letter of May 4, 1989, as follows:

> I very much regret that I will be unable to attend. But I would like you, and your fellow organizers, to know how pleased and gratified I am that you are holding this conference. My feelings stem from a number of the conferences attributes. The timing is sensational, although I think that you must share some of the credit for that aspect with Mr. Gorbachev. I am perhaps most pleased that you are involving such a wide segment of University Systemwide participants. I find remarkable the impressive collection of talent that the campuses plus the Laboratories can bring to bear on problems of first rank importance, both national and international. And finally, I think that an examination of technical avenues to confidence building is a perfect topic and one most appropriate for the technical community. The issues you will address involve all nations, and a common effort to resolve and perhaps solve them is an admirable undertaking.
>
> My very best wishes for a successful conference.

Dr. Kane's wishes for a successful conference were fully realized.

The keynote addresses by Senator Pete Domenici and Congressman George E. Brown, Jr., merit our special thanks. They are to be found beginning on pages 120 and 65, respectively. The summary address of the Conference by S.P. Kapitza begins on page 201. Workshop Summaries begin on page 478.

Papers in these Proceedings are ordered alphabetically by first author's last name. This choice seemed preferable to an attempt to organize the volume by subject matter, which is diverse, or by following the organization of the Program of the Conference, see pp. ix-xvi. We belive that reference to the Program and the use of the running headlines with author's names in the body of the text will make easy the finding and reading of a set of papers on a connected body of subject matter.

The fact that we were able to issue the proceedings so soon after the Conference must be credited to the editors, as well as the authors. They volunteered their time and expertise and allocated very high priority to publication of this volume. Our special thanks to Dr. Allred for coordinating the publication effort.

Not to be forgotten are the hard-working individuals who provided the behind-the-scenes support to those attending the Conference. Ms. Molly Cernicek spent most of her time on these duties for the better part of a year. Typing and secretarial assistance were provided by Ms. Ruby Singer and Ms. Fin Kasik. Ms. Ann Gajewski, of the LANL Protocol Division, helped with arrangements at St. John's College Conference Center and with registration activities. To the staff of St. John's College we are indebted for their gracious treatment of all attendees, especially those who stayed at the Conference Center. Last but not least we thank the LANL Travel Office for all of their help and expertise.

LOUIS ROSEN

For the Organizing Committee

INTERNATIONAL COOPERATION IN PLANNING AND PREPARING FOR NUCLEAR ACCIDENTS OR RADIOLOGICAL EMERGENCIES

by

Ephraim Asculai
International Atomic Energy Agency

INTRODUCTION

In September 1986 a special session of the General Conference of the International Atomic Energy Agency passed two conventions which relate to activities upon the occurrence of nuclear accidents or radiological emergencies. These conventions are the Convention on Early Notification of a Nuclear Accident and the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency. In a way the passing of these two Conventions in the General Conference was a climax to a large preparatory work and international coordination which achieved these two remarkable Conventions in a very short time. These Conventions are, on the one hand, the climax and on the other were the beginning of a very long work both in the International Atomic Energy Agency and in the Member States in order to implement these two Conventions. The implementation of the Conventions is the subject of this paper. However, some work on the international scale in preparing and responding to accidents in the Atomic Energy Agency already has its roots sometime back.

Since 1959, the Agency has had a relatively simple action plan by which it would, upon request, arrange to provide assistance to any Member State following an accident involving radioactive material. This plan may have been adequate for relatively small, localized emergencies. However, it was never called upon to mobilize the Agency for responding to accidents involving nuclear power facilities or relatively extensive radiological emergencies involving radioactive materials.

The concept of having such an Agency plan was basically sound, but it was never seriously put to the test of responding to a real accident or emergency such as those which have occurred in recent years. The number of nuclear facilities and the use of the radioactive materials have expanded to the statistical point where accidents and emergencies are occurring with increasing frequency. This requires a re-evaluation of the Agency's role and obligation to provide assistance when requested or, in the absence of a request, when it feels morally obliged to offer its "good offices" regarding assistance.

Since 1979, concern about an adequate emergency planning and preparedness posture on the part of Member States and the Agency was manifested by accelerated activities in this specific area and in nuclear safety and radiation protection in general. These activities occurred after the two most serious nuclear accidents of record at the Three Mile Island (TMI) and Chernobyl nuclear power plants. TMI ultimately resulted in direct action by the Agency's Board of Governors and the Secretariat leading to two advisory documents. Chernobyl resulted in the adoption in 1986 of the two Conventions, both of which were based on the two advisory documents issued after TMI. These Conventions levy specific obligations and responsibilities on States Parties and on the Agency.

THE EARLY NOTIFICATION AND THE ASSISTANCE CONVENTIONS

In order to review some of the activities which followed we have to look into the requirements of the two Conventions. For the Early Notification Convention, it is specified in the event of an accident . . . the State Party shall:

(a) forthwith notify, directly or through the International Atomic Energy Agency, those States that are or may be physically affected and the Agency of the nuclear accident, its nature, the time of its occurrence and its exact location where appropriate; and

(b) promptly provide the States, directly or through the Agency, and the Agency with such available information relevant to minimizing the radiological consequences in those States.

The information to be provided comprises the following data as then available to the notifying State Party:

(a) the time, exact location where appropriate, and the nature of the nuclear accident;

(b) the facility or activity involved;

(c) the assumed or established cause and the foreseeable development of the nuclear accident relevant to the transboundary release of radioactive materials;

(d) the general characteristics of the radioactive release, including, as far as is practicable and appropriate, the nature, probable physical and chemical form and the quantity, composition and effective height of the radioactive release;

(e) information on current and forecast meteorological and hydrological conditions necessary for forecasting the transboundary release of the radioactive materials;

(f) the results of environmental monitoring relevant to the transboundary release of the radioactive materials;

(g) the off-site protective measures taken or planned;

(h) the predicted behavior over time of the radioactive release.

Such information shall be supplemented at appropriate intervals by further relevant information on the development of the emergency situation, including its foreseeable or actual termination.

The functions of the Agency following a notification by a Member State of a nuclear accident are also specified in the Convention. They are that the Agency shall:

(a) forthwith inform State Parties, Member States, other States that are or may be physically affected as specified in Article 1 and relevant international intergovernmental organizations of a notification received, and

(b) promptly provide any State Party, Member State, or relevant international organization, upon request, with the information received (see above).

In order that the Agency be able to fulfill its main duty under the Convention, mainly notifying the Member States, all Member States are required to make known, both to the Agency and to other State Parties, its competent authorities and point of contact responsible for issuing and assuring the notification and the subsequent information which was referred to above.

The requirements of the Assistance Convention are that the States Parties shall co-operate among themselves and with the Agency in accordance with the provisions of this Convention to facilitate prompt

assistance in the event of a nuclear accident or radiological emergency to minimize its consequences and to protect life, property, and the environment from the effects of radioactive releases.

In the more practical sense, the Convention can be employed by a direct request from a Member State or State Party. The Convention specifically states that if a State Party needs assistance in the event of a nuclear accident or radiological emergency, whether or not such accident or emergency originates within its territory, jurisdiction or control, it may call for such assistance from any other State Party, directly or through the Agency, and from the Agency, or, where applicable, from other international organizations.

The obligations of the Agency under this Convention are:

(a) collect and disseminate to State Parties and Member States information concerning:

  (i) experts, equipment, and materials that could be made available in the event of nuclear accidents or radiological emergencies;

  (ii) methodologies, techniques, and available results of research relating to response to nuclear accidents or radiological emergencies;

(b) assist a State Party or a Member State when requested in any of the following or other appropriate matters:

  (i) preparing both emergency plans in the case of nuclear accidents and radiological emergencies and the appropriate legislation;

  (ii) developing appropriate training programmes for personnel to deal with nuclear accidents and radiological emergencies;

  (iii) transmitting requests for assistance and relevant information in the event of a nuclear accident or radiological emergency;

  (iv) developing appropriate radiation monitoring programmes, procedures and standards;

  (v) conducting investigations into the feasibility of establishing appropriate radiation-monitoring systems;

(c) make available to a State Party or a Member State requesting assistance in the event of a nuclear accident or radiological emergency appropriate resources allocated for the purpose of conducting an initial assessment of the accident or emergency;

(d) offer its good offices to the State Parties and Member States in the event of a nuclear accident or radiological emergency;

(e) establish and maintain liaison with relevant international organizations for the purposes of obtaining and exchanging relevant information and data, and make a list of such organizations available to States Parties, Member States, and the aforementioned organizations.

The following part of this paper will describe the implementation of the Convention for the Agency, for the Member States and for the international intergovernmental organizations. In order to fulfill its duties, the Agency had to set up its emergency assistance services and implement an emergency response system.

ELEMENTS OF THE EMERGENCY RESPONSE SYSTEM (ERS)

The Agency has defined and developed the planning, procedural, and operational documents necessary to assist it and its Member States in implementing the various responsibilities and functions under the two Conventions in the case of an accident or emergency.

These documents are:

(a) NUCLEAR ACCIDENT/RADIOLOGICAL EMERGENCY ASSISTANCE PLAN (NAREAP):

This plan provides the foundation for maintaining and activating the Agency's emergency response system. It is considered to be a document for internal Agency use to provide the relevant staff with basic information to enable an effective response. It is also intended that this plan provide a basic conceptual framework of planning and assumptions; concept of operations; organization and responsibilities; communications; data acquisition, handling, and dissemination; administrative, technical, and general support; coordinated training and exercises; plan maintenance, review, and implementation. Its scope encompasses nuclear accidents and radiological emergencies referred to in the Conventions. The plan's application is limited to the internal operations of the Agency.

(b) HANDBOOK OF EMERGENCY RESPONSE PROCEDURES:

This procedural document supports NAREAP with detailed internal emergency response operational procedures to activate and deactivate the ERS. It is for the use of the involved Agency staff and contains procedures governing such things as communications, notifications, activation and callup of the Agency's emergency response team, training exercises, and obtaining and rendering assistance.

(c) EMERGENCY NOTIFICATION AND ASSISTANCE TECHNICAL OPERATIONS MANUAL (ENATOM):

This manual conceptually links the Agency, relevant international organizations, State Parties, and Member States under the provisions of the Conventions. ENATOM has been distributed to competent authorities involved. It contains the text of both Conventions, along with practical operational suggestions based on internal Agency procedures for notification of a nuclear accident or radiological emergency and for offering or requesting assistance. It also contains information and guidance on communications with the Agency, relevant international organizations, and Member States; description of Agency's role and capability in "brokering" assistance; information concerning experts, equipment, materials, and services that could be made available by Member States and relevant international organizations; information on the Agency's NAREAP and the ERS; abstracts of all Agency emergency planning and preparedness, and radiation protection technical guidance publications; information on specialized national and regional medical centres worldwide collaborating with the World Health Organization (WHO); and information on points of contact and competent authorities as required by the Conventions.

ORGANIZATIONS OF THE ERS

The organizational concept for the ERS is to maintain a small permanent two-person staff. One professional is designated as co-coordinator of emergency assistance services and one technical assistant maintains the administrative and technical aspects of the system. These are embodied in NAREAP and

its attendant procedures, ENATOM, and the emergency response unit (ERU), which is the physical and communications focal point of the system. During activation of the system, other staff are also involved. When the ERS is not in activation or emergency to the Agency will normally be the United Nations Vienna International Center, Security Control Center (VIC-SCC).

The Agency established an emergency response unit (ERU) to fulfill its obligations, mainly those which come under the two Conventions. Two main types of activities are required of the ERU: (1) receiving and disseminating information provided or requested by Member States during the acute stages of a nuclear accident; and (2) providing or obtaining assistance in response to requests from Member States.

To cope efficiently and intelligently with these requirements, the ERU maintains an emergency assistance resource database; develops and maintains the software for handling and analyzing radiological monitoring results and the characteristics of the accident source; and develops the mechanisms for handling and analyzing the results of model predictions for assessing the consequences of nuclear accidents.

From a technical standpoint, the ERU must have a communications and data-handling capability; resource database; analysis methodology; and ERU and ERS operational procedures.

The ERU communications systems facilities are designed to access, and be accessible to, the specified points of contact and other official channels of States Parties and Member States. The communications facilities include: telephones with direct international dialing and automatic dialing facilities; telex (both transmission and reception); telefax (transmission only); electronic mail; and access to WMO's GTS. The GTS is to be used for the rapid transmission of a large volume of data to many points when the distribution of information is unrestricted. Also included are in-house telephone and intercommunications systems. The Agency's computer section is further preparing a computerized file-management system, designed to facilitate the rapid re-transmission of the data while, at the same time, performing quality-assurance checks of the data and storing it in files for future analysis.

The ERS, officially inaugurated on 18 January 1989, has since then been put to the test, having been activated upon a request from a Member State to supply radiation protection and medical expertise, which it did.

The ERS is continuously maintained and tested and some exercises, with some Member States' cooperation and international organization participation, are planned for later this year.

IMPLEMENTATION IN THE MEMBER STATES

The duties of the Member States are, although clearly specified, at least on the order that the Agency has set up for itself, if not for much more, since the Agency has set up only a general communication and data center. The Member States, besides implementing the requirements of the Conventions, need to set up, because of the combination of possible accidents both in their own states and in other states, an emergency response system incorporating, interalia, a monitoring system, because a situation may occur outside their jurisdiction that will have a large influence on their actions. The Agency, both under its progammatic activities and its requirements under the Conventions, is ready to assist the Member States to set up their emergency response system. It is essential for good cooperation that the communication links not only be established but that the Member States know how to utilize these communication channels and be able to receive and understand the messages that are originating both from the Agency and from other Member States.

The Member States also have to assess and to collate their own internal information on the availability of resources in their own country. This means not only very technical resources (e.g., Geiger counters, air-sampling systems), but also human resources and facilities. Human resources are necessary in many areas, from the medical and life-saving to the radiation-protection specialist and to specialists in nuclear-related fields such as radiation chemistry, nuclear engineering, etc.

These personnel are essential for good management of an accident and the technical resources are essential for understanding the situation as it is occurring. As already mentioned, the International Atomic Energy Agency has requested, and already has received, from the Member States answers to a questionnaire which details the resources in the Member States. The answers to these questionnaires have two purposes.

(a) That the Agency know what assistance can be received from these Member States in case it has to provide assistance to some other Member State, and

(b) that the Agency know what resources are in a Member State, if this Member State requests assistance, so that the assistance will not duplicate the resources but will be efficient and timely for the requesting Member State.

The Agency has collected all the information which it has received and has distributed it to the Member States in the ENATOM Manual.

INTERNATIONAL ORGANIZATIONS

In order that preparation for a nuclear accident or radiological emergency be better managed on the international scale, the involved international organizations have set up an international inter-agency committee for response to nuclear accidents. The aims of this committee are to have better preparation in case an accident occurs and, in addition to that, have better coordination between the international organizations during the time of an accident, so that the assistance rendered and the opinions and advice given both to Member States and through the media be uniform and follow consultations among the organizations.

The participants in this committee represent the Food and Agricultural Organization (FAO), the International Atomic Energy Agency (IAEA), the International Labour Organization (ILO), the United Nations Disaster Relief Organization (UNDRO), the United Nations Environmental Programme (UNEP), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the World Health Organization (WHO), and the World Meterorology Organization (WMO).

In addition to coordinating with the above organizations, the Agency can call for assistance and rely on the help of other United Nations organizations. The most important of these, for practical assistance, is the United Nations Development Programme (UNDP), which has a resident representative in most developing countries.

In addition to these United Nations organizations there is close cooperation with regional intergovernmental organizations, e.g., the Commission of European Communities (CEC).

In order to complete the picture regarding international cooperation in planning and preparing for nuclear accidents or radiological emergencies, one should mention bilateral and multilateral agreements, of which the "Nordic" agreement is one example. These agreements are usually more extensive than the demands of the two Conventions and thus promote closer cooperation.

CONCLUSION

At the present time (summer 1989) international cooperation in planning and preparing for nuclear accidents or radiological emergencies is in full swing. The road ahead is still long. Arriving at a satisfactory level of preparedness necessitates a large effort on the part of Member States, the IAEA and other intergovernmental organizations, not only in planning, but in implementing and exercising plans. However, with all the limitations of such a wide-spread effort, the first positive results can be identified.

The first one is the recognition of the importance of this problem. This is shown by the fact that about two thirds of the Member States of the IAEA have signed or ratified the Conventions. In addition, the IAEA has managed to obtain and distribute lists of contact points and lists of resources that are necessary for good international cooperation and management of emergencies.

And finally, and not of the least importance, is the good will that has emerged from the availability of information that nations are volunteering when accidents occur. Accurate information calms the public when unfounded rumors circulate, or events of little or no consequence occur.

ROLE OF IAEA SAFEGUARDS IN CONFIDENCE BUILDING

by

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INTRODUCTION

In this paper, I will examine some attributes of confidence building and connect them with how the International Atomic Energy Agency (IAEA) interacts with its member states in carrying out its safeguards function. These interactions and the structure set up to define them help maintain and strengthen confidence between the IAEA and the member states and among these states.

CONFIDENCE-BUILDING ATTRIBUTES

If one describes the confidence-building process between persons, conditions like trust, respect, and affection would be considered important. For confidence building between nations, a different set of conditions might be more accurate and practical, such as:

1. Strong national motivation to work together for a common goal based on self-interest;
2. A formal structure in which each country feels in control of their involvement;
3. Close and continuing communication at political, diplomatic, and technical levels;
4. An understanding of the positions of the other countries so each member can reasonably predict reactions to various situations; and most important,
5. A feeling that each side is upholding its part of the bargain.

PERTINENT BACKGROUND OF THE IAEA

The IAEA was founded in 1957 to promote the peaceful uses of nuclear power worldwide as part of President Eisenhower's "Atoms for Peace" initiative. The IAEA gradually took on its safeguards verification role, with a significant increase in responsibility, when the Non-Proliferation Treaty (NPT) came into effect in 1968.[1]

The IAEA is a United Nations (UN) organization, independent of the UN General Assembly, with its own membership and governing body. When a problem has been detected, the IAEA Board of Governors reports directly to the UN Security Council. The IAEA continues its promotional functions, including technical assistance, nuclear safety facilitation, and research support, in addition to the important safeguards activities. Approximately 2000 people are employed by this organization; 450 work in the Department of Safeguards. The employees are considered international civil servants, and an effort is made to give representation to most of the approximately 100 member states.[2] Internal pressure among the states keeps

the quality of the professional staff high. All professional safeguards staff have technical degrees. The IAEA is located in Vienna on the boundary of Eastern and Western Europe in neutral Austria.

The organization, location, and staff help to maintain credibility, and therefore confidence, that the IAEA can verify compliance to safeguards agreements.

CONNECTIONS BETWEEN IAEA SAFEGUARDS AND CONFIDENCE BUILDING

It should be understood that the IAEA safeguards regime aims to build confidence among politicians. It must satisfy heads of government that other member states are not diverting nuclear material to nonpeaceful uses. The IAEA uses technical means to carry out its safeguards functions always within a political framework.

Strong National Motivation

It appears that many nations have come to the conclusion that nonproliferation is in their best interest,[1] and thus they have signed the NPT, even though it is discriminatory, having different conditions for weapons and nonweapons countries, and requires giving up some national sovereignty by allowing IAEA inspectors into their facilities. In spite of this, countries have signed and implemented the treaty provisions.

The treaty provides for technical assistance in nuclear power development to developing countries. This may offer an incentive to some countries to adhere to the safeguards regime. Being a signatory also gives a country a stronger voice in international nuclear-related issues, including the debate on arms limitations among the nuclear weapons states.

For the above reasons and others, much of the world has made a commitment to IAEA safeguards. This commitment seems to glue the member states to the IAEA even in politically turbulent times.

Formal Structures

The documents describing the conditions under which IAEA safeguards will be implemented are in place. These include the NPT itself, IAEA information circulars,[3] and individual facility attachments. The documents are continually discussed and debated, but there is sufficient agreement to make the system work and for the member states to understand their responsibilities.

Close and Continuing Communication at Political, Diplomatic, and Technical Levels

The structure of the IAEA organization encourages communication, information exchanges, and involvement among a variety of different groups.

Member states maintain diplomatic missions to the IAEA and participate in board meetings and the annual general conference. The diplomats transmit political concerns to their counterparts and to the IAEA daily. The management at the IAEA has direct contact with national government agencies responsible for nuclear issues, for example, in the United States the DOE, NRC, ACDA, and State Department. On the technical level, 12 countries have support programs to develop technology to improve the inspection capability. At this level, scientists and engineers work closely with IAEA development staff and inspectors.

Finally, the inspectors interact with facility operators worldwide, carrying back current information on the state of the nuclear industry.

The communication activity within the Vienna International Center is amazing. The most descriptive analogy would be a macroscopic neural network.

The most important consequence of the communication is the improved confidence that comes from being informed. Decisions can be made on current, complete, and reliable information.

Understanding the Positions of the Member States

The interactions described above lead to an understanding between nations of their respective positions on nuclear-related issues. Because they have to work together often to resolve or at least understand sticky problems, the member states develop an appreciation for how other countries handle problems. This, in turn, gives an element of predictability to international relations, at least in the safeguards arena. Interestingly, the US and the USSR usually agree to support the IAEA role in nonproliferation. However, each country provides that support in different ways.

Guarantees Based on Verification

The verification based on inspections at nuclear facilities is the most important way in which the IAEA builds confidence.

Nuclear facilities report monthly to the IAEA on all movements and changes involving safeguarded nuclear material. The reported (declared) quantity and location of nuclear material are stored in the IAEA mainframe computer accountability system. Periodically, inspectors travel to a facility with an inventory listing. They update the listing, count all the items, and select items for verification measurements. The number of items selected is based on a statistical sampling plan designed to detect three levels of material diversion. Some measurements are made on the spot using nondestructive assay equipment, and some items are sampled for chemical analysis. Items under seal are checked for tampering, and surveillance film is collected for review back at headquarters. All this information is compiled and analyzed. The end product is an inspection report stating whether the IAEA considers the quantity of declared material to be verified or not.

These on-site inspections are performed by 190 inspectors. Considering the number of nuclear facilities worldwide, this seems to be a big job for so few people.

Two features required of the verification system are transparency and credibility. Transparency implies that the member states know and understand the inspection procedure and how conclusions are reached. The facility-specific information and measurement data are held as confidential and not released, but the IAEA does publish its methods and criteria. Credibility involves independent verification, technically sound procedures, and competent, conscientious staff. The IAEA continually strives for credibility because it is fundamental in building confidence.

CONCLUSION

The IAEA is an example of an international organization that has promoted confidence building between major nations of the world. It seems that the IAEA is successful in confidence building because the member states continue to accept the requirements imposed by the safeguards system and publicly state their faith in its credibility. The IAEA has weathered difficult political situations including having the US delegation walk out of a general conference (1982). This success is at least partly due to having certain attributes built into its structure. These include a common goal accepted by the member states (nonproliferation), a wise contract (NPT), and an appropriate organization, that strives to be credible and transparent.

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INTERNATIONAL COLLABORATION ON INHERENTLY SAFE NUCLEAR REACTORS

by

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INTRODUCTION

The absence of large-scale economic interaction between the United States and the Soviet Union, the world's two superpowers, stands in stark contrast to the development of global interdependence. Independence rather than interdependence is the norm. Political rivalry and mutual suspicion, of course, have been major factors in creating and sustaining this independence. Beyond political competition, however, the two societies have had very little in common that would produce bonds or ties capable of ameliorating political disputes. Each society today is a product of widely differing histories, cultures, economic, and political systems. As Strobe Talbott has noted, "The United States and the Soviet Union are more than adversaries; they are fundamentally alien to each other."

What the Soviet Union and the United States have in common, that makes the differences pale in comparison, is the ability to wreak uprecedented devastation upon one another, destroying civilization as we know it and jeopardizing the lives of those anywhere on the globe. To avoid such a fate it is imperative that we seek means of bringing the societies closer together, such that the launching of a nuclear attack becomes simply and unequivocally unthinkable. In speculating on what means or activities might begin to fulfill this goal, it is important to consider those that have the potential to weather the swings in Soviet-U.S. relations that we have witnessed in the past, and which we will inevitably witness in the future. Activities that bloom in a period of detente are fine, but what we ought to be searching for are those "hardy perennials" that can survive the winter as well as the spring. It would appear that such activities would have to fulfill the following basic criteria: (1) each country should place a high value upon the activity, recognizing that it meets a perceived national interest; (2) there should be a symmetry of interests and capabilities, such that each country recognizes the value of cooperation as opposed to independent actions.

It is not surprising that those searching for common ground among the superpowers have focused on science and technology activities. Despite the prevailing dissimilarities, each superpower is imbued with the faith that science and technology is the engine of economic growth and that continued support is essential to maintain one's position in the international community of nations. Science and technology transcend economic and political ideologies, providing a means of communications and approach common to both the United States and the Soviet Union. Each superpower recognizes the enormous capabilities and skills of the other. It is for these reasons that when each side finds collaboration to be within its own interest, they frequently turn to such areas as, nuclear fission, nuclear fusion, and the exploration of space.

What is suggested in this paper is that the field of nuclear fission is a logical and productive area for superpower and broader collaboration, but that the kind of collaboration characteristic of past and present activity is less than it optimally could be. Nuclear power is at a crossroads today. If governments feel that further development of nuclear power is within their countries' interest, and strong arguments can

be marshalled to support such a judgement, collaboration on a scale far more significant and dramatic is needed.

Specifically, next-generation nuclear reactors need to be built and tested—reactors that would not be encumbered with the negative public perceptions associated with current-day reactors. Reactors that hold this promise, frequently termed (although not without a little controversy) inherently safe reactors, have been the subject of rather intense discussions during the 1980s, and nuclear engineers around the globe are at varying levels of specificity in the design of such reactors. What is missing at this stage is a firm government or corporate commitment to build and demonstrate such reactors. Obviously, international collaboration is not required. Given, however, that such an endeavor would be speculative and expensive (running into the hundreds of millions of dollars) and the fact that both superpowers have an inordinate interest and expertise in this field, collaboration makes sense. What follows, therefore, is a brief elaboration of the proposal for a collaborative effort to further the development of inherently safe nuclear reactors.

INHERENTLY SAFE REACTORS

Inherently safe reactors are reactors designed to eliminate the possibility of a core melt without relying upon activation of mechanical devices or upon human intervention. In other words, their safety measures are built in through the incorporation of a passive, nonmechanical safety system—not added on. Inherently safe reactors are sometimes called "walk away" or "forgiving" reactors, meaning that operators could actually leave the premises without endangering the public. This is possible because passive safety features are based on the closest thing to foolproof systems known to man: chemical and physical laws of nature such as natural convection, gravity, thermal radiation, and other heat transfer process.

The laws of convection and heat-transfer processes used by inherently safe reactors may be as unfamiliar to most Americans as are the mechanical systems required to protect current reactors. But they are well understood by thousands of high school and university teachers who could easily confirm or deny the claims of nuclear power proponents. Still, because public perceptions are involved, these new reactors must not only be "certified" as being safe, they must *be seen as being safe.* A widely publicized demonstration wherein the primary coolant of a full-scale inherent safety unit is cut off, and the reactor is allowed to shut down harmlessly under its own means, would provide a dramatic example of inherent safety principles.

Three principle types of inherently safe reactor designs have emerged, each based upon a different coolant—water, helium gas, and liquified metal.

The process inherent ultimately safe (PIUS) reactor relies on a large pool of borated water for its safety system. The borated water that prevents the chain reaction floods the reactor through density locks that open without any mechanical intervention whenever the cooling system is disturbed. Estimates are that enough borated water can flow to the core to keep it covered for at least one week.

A family of small high-temperature gas reactors (HTGR) is graphite moderated and helium cooled. Because of their small size, residual heat can be removed by passive natural convection. Congress has prodded the U.S. Department of Energy (DOE) to spend approximately $20 million annually for several years to support design research on the modular high-temperature gas reactor (MHTGR).

DOE has also provided modest research support for liquified-metal-cooled reactors, notably: General Electric's Power Reactor Inherently Safe Model (PRISM); Rockwell International's Sodium Advanced Fast Reactor (SAFR); and Argonne National Laboratory's Integral Fast Reactor (IFR).

U.S. government support for design and some testing has been useful, but commercializing these reactors will require prototype construction and demonstration—a much more expensive proposition. Moreover, building and operating prototypes is necessary to learn about the economics of these systems. If the inherently safe reactors are to have a future, they must be both safe and economical. If off-site safety can be adequately guaranteed, reducing the regulatory burdens that have imposed enormous costs upon today's reactors should be possible. Yet this hypothesis can only be tested through actual construction and licensing.

INTERNATIONAL COLLABORATION

Given budgetary constraints and mounting concerns over global warming, the case for cost sharing is compelling. And spearheading the drive to develop inherently safe reactors should be the United States and the Soviet Union, which account for 45 percent of all the fossil-fuel carbon-dioxide emissions associated with energy production and posses fully 55 percent of the world's recoverable coal reserves.

Cost and sharing is an important element in collaboration, but there are other even more compelling reasons for jointly sponsored activities. Collaboration would give reactor development a prominence or visibility that could not be achieved through working alone. This visibility may be essential in creating a new aura surrounding nuclear power. Furthermore, collaboration would work toward cementing a more normal U.S.-Soviet relationship. The case for collaboration, therefore, rests on economic, psychological, and political grounds.

U.S.-Soviet nuclear fission cooperation is not novel, dating to a 1973 agreement pledging joint efforts to further the peaceful uses of nuclear energy. Until 1986 most U.S.-Soviet collaboration in fission took place in the fields of high-energy physics research and breeder reactors, with scientists from both countries visiting each other's distinctive research facilities. Since 1986 the Soviets have expressed greater interest in joint activities dealing directly with reactor safety. At the 1988 Moscow summit, General Secretary Gorbachev and President Ronald Reagan endorsed a memorandum of understanding outlining ten areas of potential collaboration in reactor safety, including fire protection, radiological health standards, and reactor safety assessments. Representatives of both countries have made several visits and inspections of the other's facilities.

Superpower collaboration in nuclear fission has clearly been a success to date, and its modest expansion seems fairly certain. But such low-key exchanges cannot possibly resolve the major obstacles to a significant further expansion of nuclear power. Something far more dramatic is needed; the entire issue must be placed on a higher political plateau.

Ample precedent exists for greatly increased international collaboration in nuclear energy. At the 1986 Geneva summit, Gorbachev proposed a collaborative fusion-energy research project that President Reagan subsequently supported. Even prior to 1986 there had been a history of international collaboration in fusion research extending across a number of countries (particularly European Community nations, Japan, and the Soviet Union) and differing activities, such as information sharing, personnel exchange, joint research, and joint planning. Collaboration in fusion energy has long passed the stage of political symbolism. Though U.S.-Soviet cooperation is only a small piece of the interdependent fusion effort, it dates all the way back to 1958. The years since have witnessed a steady two-way flow of scientific visits as well as some site assignments.

Nuclear fusion, of course, is potentially a very attractive source of energy. Like fission, it will not emit carbon dioxide into the atmosphere but, unlike fission, will probably not produce troublesome waste.

Fusion's biggest liability today is the very long lead time necessary to determine whether it can become a viable, economic energy source. Demonstrations of a prototype commercial fusion reactor is at least three decades away, according to a 1987 Office of Technology Assessment (OTA) evaluation of fusion energy, contained in the report *Starpower: The U.S. and the International Quest for Fusion Energy*.

Further, even if success is achieved, the OTA panel predicted, fusion will not make an appreciable impact on energy supplies until the middle of the next century. Cooperative efforts, therefore, are needed to sustain research and development tasks, but they cannot be justified as a response to impending climate change.

A collaborative effort in nuclear fission, on the other hand, could bear fruit relatively quickly. A prototype reactor could be built and tested in the 1990s, with others for a commercial reactor beginning at the turn of the century.

Fusion cooperation provides a handy model for organizing a collaborative development effort on inherently safe reactors. In response to the Heads of State agreement signed in 1986, DOE proposed a multilateral three-year joint planning program designed to better understand the issues involved in developing a next-generation engineering test fusion reactor. Countries working on the International Thermonuclear Experimental Reactor (ITER) project would jointly define the project's scope, draw up a conceptual design, and coordinate the research needed to produce the final design. In April 1988, the United States, the Soviet Union, the European Community, and Japan agreed to go forward with the ITER. A full-time managing director has been appointed from each participating nation and the project has been organized under the auspices of the International Atomic Energy Agency (IAEA). DOE estimates the U.S. share of this $150-200 million project to be $15-20 million. Although the ITER project is limited to design, many hope that successful collaboration in this phase will lead to construction of a demonstration reactor .

Essentially the same countries involved in the ITER program could participate in the inherently safe reactor program, for the nations with fusion expertise have also made important strides in fission. One might also wish to enlist such countries as China and India, which have considerable expertise, but more important, possess abundant reserves of fossil fuels and are expected to play important roles in global energy use and climate change.

Nations agreeing to participate might proceed step by step toward actual construction of a prototype. Before scientists and engineers embark upon the venture, two preliminary decisions should be made: (1) the kind of reactor to be built, either water, gas, or liquid metal; and (2) the specific safety performance standards the chosen reactor should attain. Financial constraints require the choice of a single reactor and there is considerable precedent for making such choices among competing technologies. Safety performance standards should be set forth in terms clearly understandable to the public (ruling out the use of probabilistic risk assessment in standard setting) and should be tied to inherent or passive safety features (for example, the number of days that passive safety systems (which must be able to protect the integrity of the reactor core before human intervention is required).

Once these fundamental choices have been made, the fission collaborative effort could move on to the ITER stage—that is, producing a conceptual design of a specific safety performance standard the chosen reactor should attain. Financial constraints require the choice of a single reactor, and there is considerable precedent for making such choices among competing technologies. Safety performance standards should be set forth in terms clearly understandable to the public (ruling out the use of probabilistic risk assessment in standard setting) and should be tied to inherent or passive safety systems must be able to protect the integrity of the reactor core before human intervention is required).

Once these fundamental choices have been made, the fission collaborative effort could move on to the ITER stage—that is, producing a conceptual design of a reactor and identifying key research areas. Only after this stage has been completed should actual construction of a prototype begin.

Such a proposal was floated and supported by the Soviet Union shortly after Chernobyl. The IAEA considered sponsoring the venture but eventually demurred when countries with substantial existing nuclear-power investments, including the United States, made clear their opposition. But it is time to revive the idea. And if the Soviets and the United States signed on, the European Community and Japan would surely follow. Moreover, no new institutions need be created. A model for restructuring cooperation already exists. Only the will to use it is lacking.

The benefits of international collaboration could be substantial, including cost and risk sharing that could greatly accelerate reactor construction and testing, as well as the political and diplomatic glow that would come from finding an area where U.S. and Soviet interests really do coincide. On the negative side would doubtless be the host of administrative or transaction costs that necessarily arise with projects carried out across national boundaries and involving different legal systems, as well as a loss of decision-making autonomy that each participating country will suffer. Additional complications will inevitably arise regarding such issues as intellectual property rights, selection and assignment of personnel, ownership of equipment, and other financial and legal matters.

Technology-transfer concerns and the establishment of an equitable dispute resolution mechanism are still other issues that will have to be dealt with. Yet these are issues that the fusion community has already faced and come to terms with. It may be that these concerns will be more severe in fission since, unlike fusion, a large-scale commercial-industrial network already exists.

Moscow and Washington could link such a collaborative nuclear-power effort to future reductions in nuclear arms, thereby dramatically raising its profile. Specifically, the effort could be dramatized as a second Atoms-for-Peace initiative. When President Eisenhower originally presented the idea to the United Nations General Assembly 35 years ago, he called on both nuclear superpowers to pool the stockpiles of fissionable material they had accumulated from weapons programs and use them to generate electricity in a series of new civilian reactors. But the idea fell on deaf ears, with the result being the enormous stockpile of nuclear weapons that exists today.

A second Atoms-for-Peace proposal, based upon a new, more forgiving generation of reactors and a superpower commitment to slash military stockpiles, would have enormous global appeal. The viability of civilian uses of nuclear-energy would be enhanced at the same time that its military role would be reduced. This initiative would begin to fulfill the obligations the superpowers incurred under Article 6 of the Non-Proliferation Treaty to work toward the cessation of the arms race and nuclear disarmament.

Yet the temptation to link U.S-Soviet civilian nuclear energy collaboration and arms control should be resisted, because the achievement of deep cuts in nuclear arsenals is by no means a foregone conclusion. Making progress in developing new reactors contingent upon arms reductions could stall the inherent safety campaign. Moreover, the higher the program's profile, the greater the dangers that it will be held hostage to the vicissitudes of U.S.-Soviet relations. Future reactor development is eminently important enough to stand on its own merits, and in general, linkages with other issues should be avoided.

LOOKING AHEAD

Nuclear power's future is in doubt. Major technological change is essential for the atom to become part of the answer to growing global electricity needs and to combating fossil-fuel burning. As reported in the February 18, 1988, issue of *Nucleonics Week*, recent safety inspections by teams of international specialists have generally found selected nuclear plants around the globe to be capably managed and run. Still they report the disturbing absence of a "safety culture" at many facilities, even after the dramatic accidents at Three Mile Island in Pennsylvania and Chernobyl. Inherently safe reactors are probably a better bet in ensuring safety than relying upon producing changes in organizational and human nature.

Supporters of inherently safe reactors will have to be candid about what such plants will and will not do. Inherent safety does not mean absolute safety. No facility containing large amounts of radioactive materials can be foolproof. Inherent safety does not necessarily translate into economic, cost-effective power. It would have no impact on widespread concerns over nuclear-waste transportation and disposal or weapons proliferation. Hence, improvements in reactor technology may not be a sufficient condition for widespread public acceptance of nuclear power, although they are probably a necessary condition. But with so few long-term energy options available, it would be foolish to turn our backs on nuclear power safety simply because a panacea for all aspects of public concern does not exist today.

GEOLOGIC CONTAINMENT OF RADIOACTIVE WASTE

by

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INTRODUCTION

Geologic containment for the disposal of radioactive waste has been chosen or is being considered by many nations. Geologic disposal provides the multiple-barriers concept for containment of long-lived radioactive fission products and actinides in the waste material. The multiple barriers concept can be divided into two subsystems, 1) the engineered barriers and 2) the natural barriers.

The engineered barriers consist of: the waste form as a very slow dissolving material; the canister containing the waste form, providing complete containment as long as the canister is not breached by corrosion or physical destruction; a buffer and/or backfill material emplaced between that canister and the natural surroundings, which provides for slow migration of escaping radionuclides; and the last engineered barriers being any seals used to seal likely pathways such as boreholes, shafts, tunnels, or fracture zones.

The natural subsystem provides the final barrier to the escape of radionuclides to the accessible environment. The natural system, under expected conditions, could induce transport of radionuclides by interactions with groundwater and also, in the case of the unsaturated zone of Yucca Mountain, Nevada, through transport of volatile radionuclides in the gas phase. The natural system acts as an effective barrier to radionuclide migration because chemical reactions retard the movement of chemical species in the groundwater. These reactions include the precipitation and co-precipitation of stable crystalline phases; the reactions between species in solution with the surfaces of minerals (i.e. ion exchange, adsorption, etc.); and the formation and destruction or filtration of colloids. A model calculation by de Marsily, et al[1] of five hypothetical hydrogeological settings demonstrated that even under the most favorable hydrological conditions, retardation by chemical reactions was most effective. Therefore, it is very important to understand both the chemical and physical processes involved in the migration of radionuclides.

The performance assessment of the repository system requires the modeling of physical and chemical processes, many of them coupled. It also requires predictions of how this engineered and natural system will behave over a very long time (10,000 to 1 million years). By the very nature of the complexity of the processes that need to be understood and the long time scales over which predictions will be made, large uncertainties with respect to the outcomes are inevitable.

Research programs must seek to reduce uncertainties in these predictions by way of site characterization, research into understanding the physical and chemical processes acting within this system, and the development of techniques of modeling the processes of radionuclides migration within the natural system.

In this paper we present results of our work and outline our thoughts on resolving the uncertainties associated with the nature of the solubilities and speciation of actinides, the formation of radiocolloids, the sorption behavior of fission products and actinides, and the transport mechanisms of advection, diffusion, and dispersion for radionuclides under environmental conditions thought to exist at Yucca Mountain, Nevada.

SOLUBILITY

It is not practical to measure the solubilities of all radionuclides that may exist in nuclear waste under all conditions that may occur at the repository and surroundings. Therefore, the technical approach used is based on three criteria: (1) select radionuclides that are expected to be present in large quantities, (2) select radionuclides that have solubility limits, and (3) select conditions that will bound expected conditions at the repository and along flow paths to the far field.

The radionuclides selected for initial study are neptunium, plutonium, and americium. These elements are expected to be present in the largest quantities, and they have the longest radioactive half-lives. Measurements are also planned for uranium, thorium, radium, zirconium, tin, and nickel.[2] Radionuclides that have high solubilities in near-neutral pH groundwaters, such as cesium and technetium, were not selected. It is expected that the solubilities of cesium and technetium will not be determined by solubility limits but rather by dissolution rates of the waste package and adsorptive interactions with geologic media.

The repository and far-field conditions that could affect the solubilities of radionuclides under consideration include numerous factors: temperature, pH, Eh, radionuclide oxidation state, concentration of complexing ligands, ionic strength, radiation field, etc. We will measure directly the "apparent" solubilities of radionuclides in groundwater samples obtained at the Yucca Mountain site. Groundwater samples with compositions that bracket the range of expected conditions at Yucca Mountain[3] will be taken from two sources. Water from Well J-13 is expected to be representative of the unsaturated zone near the proposed emplacement horizon (pH of 7, moderately oxidizing Eh, and a total carbonate ion concentration of $\sim 10^{-3}$ M). Water from Well UE25p#1 taps the carbonate aquifer that underlies the repository horizon (pH of 6.7, moderately reducing Eh). This water has an ionic strength and total carbonate content an order of magnitude higher than those in J-13 water.[3] The apparent solubility measurements will be conducted at 25, 60, and 90°C. The pH values selected for making measurements are 6, 7, and 8.5. This presupposes that only order-of-magnitude changes in the hydrogen ion concentration can be expected from the original value of the Yucca Mountain groundwater. Since the carbonate-ion concentration will be maintained at the amount the water had in its original state, carbon-dioxide partial pressure and pH will be maintained throughout the experiments. The pH-stat is described in detail elsewhere.[4] Some experiments are planned using various ionic strength solutions since some evidence suggests that water in the unsaturated zone may have high concentrations of dissolved species. Also planned are experiments using two different isotopes of the same element (e.g. ^{239}Pu, $t_{1/2}=2.41 \times 10^4$ yr and ^{242}Pu, $t_{1/2}=3.76 \times 10^5$ yr) to investigate the effects of different radiation fields. The Eh and concentration and speciation of the radionuclides are measurable parameters dependent on the conditions outlined above. In these apparent solubility experiments, upper and lower limits will be determined in most cases by approaching the solubility from both oversaturation and undersaturation. Therefore, if true thermodynamic equilibrium is not attained, then the solubility range will be bracketed.

SPECIATION

Speciation is strictly defined as (1) the identity of the radionuclide, (2) determination of its oxidation state, and (3) the formula and/or structure of the ionic and/or soluble complex. Speciation can be determined to a lesser degree by determining only the oxidation state(s) of the radionuclides. Although apparent solubility measurements will provide limits for radionuclide concentrations under specific groundwater conditions, they cannot possibly provide data for all forseeable groundwater conditions. Therefore, a

fundamental thermodynamic characterization of radionuclide speciation is required to bridge any gaps in those data acquired from direct solubility measurements and to provide the fundamental thermodynamic constants needed for the solubility modeling task. In this study we will attempt to identify the important complexes of the radionuclides and their complexation quotients. Ogard and Kerrisk[3] report that carbonate ions are the principal potential complexing agents in the Yucca Mountain groundwater for the actinide elements uranium, neptunium, plutonium, and americium. These actinides, which typically have quite low solubilities in near-neutral groundwaters, can be strongly complexed by "hard" (ionic) oxygen-donor ligands to form species that have greatly increased solubility limits. For this reason, the speciation study will focus on the carbonate complexes of actinides, but additional work is planned to study other potentially important complexing ligands commonly found in groundwater (e.g., fluoride, phosphate, humates, etc.).

Carbonate-ion speciation of the actinides under relevant repository conditions involves equilibria such as

$$Pu^{4+} + mHCO_3^- + nH_2O \rightleftharpoons [Pu(OH)_n(CO_3)_m]^{4-n-2m} + (n+m)H^+. \quad (1)$$

It is difficult to study these equilibria directly using conventional analytical methods because at environmentally relevant pH values, the concentration of Pu^{4+} is extremely low and well below the sensitivity limits of conventional methods. We are currently pursuing two of the most promising approaches to dealing with this problem. The first approach is the method of competitive complexation.[5] This method uses conventional electronic absorption spectroscopy to obtain speciation data. This approach requires deviation from site-specific conditions so that sufficiently high radionuclide concentrations (10^{-3} M can be maintained and detected by absorption methods. To bridge the gap between the well-characterized free ion, such as Pu^{4+} at low pH values, and the highly complexed hydroxycarbonate complex at high pH values, an intermediate competitive complexing ligand is used. We use citrate ion for this study. Previous work shows that carbonate ions successfully compete with citrate ions for the coordination of actinides. Three steps are required in this study; we must investigate (1) the pure carbonate/actinide system, (2) the pure citrate/actinide system, and (3) the mixed carbonate-citrate/actinide system. This will ultimately permit expression of the carbonate formation constants for Equation 1. in terms of the principal radionuclide species present in solution (e.g., Pu^{4+}).

The second approach to speciation studies does not use conventional analytical methods. We are developing ultra-sensitive laser-based spectroscopic techniques for direct spectral detection of species under relevant site specific conditions at ambient concentrations ($< 10^{-8}$ M). These techniques include the absorption-based probes, photoacoustic spectroscopy (PAS), the related method of photothermal deflection (PDS), and the complimentary, emission-based probe, laser-induced fluorescence (LIF) spectroscopy. Ultimately, electronic spectra are obtained by all of the above methods and the goal is to extract structural information. The electronic spectra of actinides are dominated by characteristically narrow *f-f* transitions that are quite sensitive to electronic environmental changes brought about by the perturbation of the complexed ligand. However, the relationship between spectral signatures and structures must generally be established empirically. Accordingly, part of our task will be to establish these spectral signatures for the various actinide species extant under site-specific groundwater conditions.

COLLOIDS

A subtask of the speciation task is the study of colloid formation, characterization, and stability. The potential for radionuclide movement in groundwater is based not only on soluble ionic species but on colloidal particulates as well. Additionally, these colloids could break up to form ionic species as an additional source of soluble radionuclides.

There are essentially three types of colloids: radiocolloids, natural colloids, and psuedocolloids. Radiocolloids are pure particles of the radionuclides. Natural colloids are particles of natural minerals, which are generally not radioactive. Psuedocolloids are natural colloids that have been "combined" with ionic or solid forms of radionuclides. In the solubility/speciation task, we will concern ourselves only with true radiocolloids.

To assess the potential for radiocolloid transport, information is needed concerning the likelihood of colloid formation under water conditions at the Yucca Mountain site and the stability of colloids once formed. Two radionuclides that may form stable colloids under these conditions have been identified: plutonium and americium. To understand the behavior of these colloids in Yucca Mountain groundwater, it is important to study both their physical and chemical properties. The most important physical characteristics are particulate size, density, and bulk charge. These characteristics determine transport/retardation mechanisms such as filtration, adsorption, sedimentation, etc. The most important chemical properties are chemical reactivity and colloid structure. A host of analytical methods are being brought to bear on this study including absorption, diffuse reflectance, and auto-correlation spectroscopies, centrifugation, filtration, chemical and electrochemical redox methods, and x-ray diffraction and absorption fine-structure methods.

SORPTION

The sorption studies are designed to obtain values for sorption coefficients for use in performance-assessment calculations and to obtain insight into the mechanisms by which various radionuclides sorb onto tuffaceous materials. Such insight will enhance confidence in use of the empirically measured sorption coefficients. Thomas[6] has compiled a database of sorption ratios obtained by batch techniques for most of the important radionuclides in spent fuel. The ratios in this database are for certain rock types and groundwaters found in the Yucca Mountain site. Many of the coefficients in the database, particularly those for the actinides, are not sufficiently reliable to be used in performance-assessment calculations in support of a license application. The following discussion outlines the present uncertainties in the database and outlines our approach regarding their resolution.

EXPERIMENTAL ARTIFACTS

Batch sorption experiments are conceptually simple and basically involve contacting a given volume of groundwater from the site, spiked with the radionuclide(s) of interest, with a portion of crushed solid material either from the site or representative of some mineral species present within the site. After some predetermined contact time, the concentrations or radioactivities of the elements of interest are measured in the solution and solid, and a sorption ratio is calculated.[7]

Experimental artifacts that can complicate the interpretation of the data obtained include dissolution of the substrate (i.e., crushed rock) during the experiment and precipitation. Dissolution of the substrate influences the measured sorption ratios primarily through the formation of colloidal and other fine particulates (i.e., disaggregation). The formation of colloids or fine particulates is problematic if they cannot be efficiently separated from the solution prior to the concentration analysis.[8] For radionuclides with high sorption coefficients, small amounts of colloid or particulate material remaining in the solution will not only result in underestimation of the sorption coefficient but will complicate the interpretation of the experimental data in terms of possible sorption mechanisms. We have found that ultrafiltration (i.e., 0.03 micron pore size) appears to remove most of the colloidal material from solution. Ultracentrifugation appears to be a less efficient technique for the solid-liquid separations.

Precipitation can also have an appreciable effect on the measured sorption ratios, particularly for elements such as the rare earths, americium, and plutonium. The solubilities of compounds of the americium and plutonium actinides in Yucca Mountain groundwaters have only recently been quantified to an acceptable level.[9] The new results indicate these solubilities are significantly smaller than previously thought. Because the sorption ratios for americium and plutonium reported in Thomas[6] were obtained with solutions having higher concentrations than the measured solubilities, these ratios are called into question. We have initiated a new set of experiments using solutions that have concentrations below the current estimates of solubilities for these elements. This poses an analytical problem in that the solution concentrations of these elements in a typical sorption experiment tend to be very low because these elements have rather large sorption coefficients. To analyze these concentrations we have developed mass-spectrometric isotope-dilution procedures that allow accurate determination of americium and plutonium down to the picogram level.

BATCH LABORATORY EXPERIMENTS VERSUS FIELD SETTING

Because the hydrologic regime in Yucca Mountain is complex, sorption ratios measured in the laboratory on crushed rock material must be used with caution. Factors that could affect the applicability of these ratios include (1) fracture versus matrix flow, (2) variability of substrate composition, (3) variability of groundwater composition, (4) changes in water/rock ratios, (5) the number of sorption sites accessible to the flowing groundwater in crushed versus in-situ rock, (6) colloid transport, (7) sorption reaction kinetics, and (8) complex source term (i.e., waste package) solutions. Although resolution of these issues will involve the results of various types of investigations, appropriate sorption experiments are a prerequisite.

The first two problems can be addressed largely through batch experiments on samples of pure minerals found along fractures and within the matrix of rock units in Yucca Mountain. Factor number three can be bounded by experiments involving the end-member water compositions presently found within Yucca Mountain, or anticipated in the future, and pure minerals or whole-rocks. Changes in water/rock ratios can be addressed with isotherm measurements on appropriate rock and mineral samples.[7] Data on the number of sorption sites available in in-situ rock versus crushed rock can only be obtained by carrying out laboratory and field experiments involving solid rock. Because these experiments are difficult to carry out and interpret, their number will be much more limited and they must be designed to provide the maximum probability for success. Batch-sorption experiments can be used to further these goals. Colloidal transport complicates the application of sorption ratios in transport calculations because colloids offer an independent mode of transport that is not addressed in the typical sorption experiment. However, batch-sorption experiments can measure the degree to which important radionuclides are sorbed on the colloids once the colloids are identified in sufficient detail. Sorption kinetics can be studied directly by batch experiments carried out in a

time series.[10] The results of such studies can be compared with the results of column experiments in which the flow rate is a variable.

SORPTION MECHANISM

Understanding of the mechanisms or reactions by which radionuclides sorb to geologic materials will aid in the validation of empirically determined sorption ratios and improve confidence in the application of the ratios. Possible sorption mechanisms appropriate to the Yucca Mountain site include: (1) ion exchange on minerals such as clays and zeolites, (2) surface complexation reactions on iron and manganese oxides and oxyhydroxides, framework silicates, such as quartz and feldspar, and possible phosphates and carbonates, and (3) precipitation in solid solutions of carbonates, phosphates, or other low temperature minerals. Ion exchange reactions in minerals such as clays and zeolites are well documented and theoretically understood.[11] For these reactions, the sorption ratios determined on crushed samples are not very different from ratios determined on solid samples[12] because the exchange sites are largely intracrystalline. Therefore, the value of the sorption coefficient for simple cations in given rock is largely a function of the zeolite and clay content of the rock[7].

The behavior of the americium, plutonium and neptunium actinides appears more complicated as no simple correlations between sorption ratios and the abundances of the major ion-exchange minerals have been observed.[7] These elements, in complexed form, may sorb dominantly by surface complexation reactions. Iron and manganese oxide and oxyhydroxide minerals appear to have a strong affinity for these elements, presumably as a result of such reactions.[13] Because americium and plutonium have rather low solubilities in dilute groundwater solutions, studies of sorption mechanisms for these elements are difficult to carry out without using oversaturated solutions. However, the higher solubility of neptunium compounds have allowed the use of spectroscopic techniques such as EXAFS and XANES in the investigations of sorption mechanisms.

The mechanisms by which anionic species sorb is also of great interest because some important radionuclides, such as technetium, are dominantly in anionic form in environments representative of the Yucca Mountain site. Although the sorption of these species is likely minimal, it is important to measure the ratios as accurately as possible. In this regard, the know affinities of iron and manganese oxide and oxyhydroxide minerals will be investigated in some detail.

RADIONUCLIDE TRANSPORT

The theory of transport through porous media was developed primarily for chemical engineering. [14] The theoretical methods were developed with the principal purpose of designing efficient separations processes for the chemical industry using chromatographic columns. Chromatographic columns are generally homogeneous with respect to both hydraulic properties, i.e., porosity and permeability, and chemical properties. Transport in geologic media is, on the other hand, complex hydrologically and chemically. Hydrologists have successfully applied the principles developed for column chromatography using the simplifying assumption of a representative elementary volume, REV.[15] However, the assumption of an REV is only valid under special circumstances. A general approach to modeling transport in complex hydrologic systems has yet to be developed.

The problem is to develop an approach that minimizes the level of detail required to make predictions within a required level of certainty. Modern stochastic models[16,17,18] capable of calculating the transport of conservative tracers describe the heterogeneity of aquifers in terms of the covariance of the permeability distribution. Spatial covariance is a property observed in fractal geometry[19] and other nonlinear phenomena, such as cellular automata. This opens many avenues for generating realistic models of hydrologic transport. The effect of the spatial variation of the geochemical and/or sorptive properties with respect to transport has not been calculated. A concern in terms of making accurate predictions of radionuclide migration is the effect of covariance between permeability and sorption—for example, if the highly sorptive minerals, such as smectites, correlated with zones of low permeability. Then the radionuclides contained in the fastest water would, in addition, have a retardation factor below average. This could greatly increase the observed dispersion and lead to early breakthrough of small quantities of radioactive waste.

The dynamic transport task has, as its primary mission, the task of testing the assumptions made in the theory of chromatography and hydrologic transport by experimentally observing the transport of radionuclides in laboratory to field-scale experiments, and it has a secondary mission of validating the sorption results in tuff columns of varying complexity. The simplest experiments are performed with crushed tuff uniformly packed in acrylic columns. These experiments use crushed tuff prepared in the same manner as the crushed tuff used by the sorption task. Significant discrepancies could indicate the presence of coexisting chemical species of the same element, colloid formation, and/or pseudocolloid formation. The kinetics of sorption can be studied by varying the water velocity and measuring the dispersion of the breakthrough curve as a function of velocity.

The results of crushed-tuff columns have yielded the following conclusions. The observed retardation factors for alkali metals and alkaline earths have agreed with those predicted from batch sorption measurements of K_d using the equation,[20,21]

$$R_f = 1 + \frac{K_d \rho}{\epsilon}.$$

The neptunium and americium actinides, on the other hand, have exhibited unretarded breakthrough.[22] For americium the amount that elutes early is a small fraction, usually $\sim$ 1 percent of the total americium injected.

The next level of complexity is to perform radionuclide migration experiments with intact tuff columns. These columns will not have the hydrologic simplicity that the uniform packing of sieved crushed tuff provides. They will, however, be free from the uncertainty that crushing causes in terms of the surface properties of minerals. These samples retain the natural hydrodynamic dispersion (valid for the laboratory scale) for porous flow through the tuff matrix. These experiments have produced interesting results. Samples of densely welded tuff from the Topopah Spring member, Yucca Mountain, Nevada have exhibited elution curves that cannot be fit to the conventional advection-dispersion equation, ADE.[23] The curves can be fit however with a time dependent equivalent dispersion coefficient.[24] This phenomenon was theoretically shown to be the result of the spatial distribution of permeability by Matheron and de Marsily.[16] The most dramatic consequence of the time-dependent dispersion is the effect on the prediction of breakthrough times for sorbing tracers. If the conventional ADE is employed to predict the breakthrough of strontium, the expected breakthrough in the solid tuff column would be at $\sim$1.5 years, based on batch sorption measurements. The actual breakthrough occurs within a few weeks of the start of the experiment. This is a discrepancy of greater than an order of magnitude. If the dispersion is given a time dependence the elution curve can be fit with the measured batch sorption coefficient. The observation of time-dependent dispersion in laboratory-scale migration experiments has provided new insight into the effect of heterogeneity on the

retardation of sorbing radionuclides. Time-dependent dispersion has been observed in the tritium elution from the CAMBRIC field test in tuffaceous alluvium on the Nevada Test Site for the Hydrology Radionuclide Migration Project.[25] The question that arises from these column experiments is when can one expect to observe the elution of sorbing radionuclides from CAMBRIC.

The next level of complexity is achieved with fractured tuff. In fractured rock the fluid flows through discrete fractures with a characteristic dispersion dominated by the variation in permeability within the fracture. Tracers will diffuse into the rock matrix perpendicular to the fracture, as first pointed out by Neretnieks.[26] Radionuclide-migration experiments in saturated tuff fractures have confirmed the importance of matrix diffusion. Elutions of conservative tracers can be described adequately by the analytic solution to the advection dispersion equations of Tang et al.[27] Adjustment of the fracture aperture from the cubic law aperture determined from the fracture permeability is required to fit tracer data in some fractures. Elutions with sorbing tracers have exhibited some early breakthrough due to pseudocolloid formation or channeling. It may be possible to model the latter with time-dependent dispersion in the fracture. Colloidal tracers have exhibited a peculiar shift in apparent fracture aperture with colloid diameter. This phenomenon has not been fully explained but is possibly the result of channeling. More transport experiments with tuff fractures and more detailed characterization of the water flow paths through the fracture are required to advance the understanding of radionuclide migration in discrete fractures.

CONCLUSIONS

In summary, we are performing research on chemical and physical processes important to conducting a performance assessment of the Yucca Mountain Site, Nevada. The information generated will increase the confidence and decrease the uncertainty in the long-term predictions of radionuclide migration. The specific research being conducted includes:

1. Experimental determination of solubility limits of fission products and actinides, including the collection of thermodynamics data.
2. Experimental determination of chemical speciation of important fission products and actinides through the use of new spectroscopic methods.
3. Experimental determination of the size, structure, and chemical behavior of radiocolloids.
4. Basic understanding of factors leading to uncertainty in the sorption database and development of new experimental techniques and methods to reduce these uncertainties.
5. Analytical and experimental program to understand basic sorption mechanisms (e.g. EXAFS).
6. Basic understanding of factors leading to uncertainty in the transport mechanisms of advection, diffusion, and dispersion through the use of experiments and theory development.

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SAFETY ASPECTS OF EVOLUTIONARY AND ADVANCED REACTORS

by

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INTRODUCTION

Currently, there is renewed interest and discussion in the U.S. on the use of nuclear power for the generation of electricity. This has come about, not only from concerns about global warming, acid rain, and clean air, but also from advances over the past several years in the development of future reactor designs with the potential for enhanced safety beyond the level obtained in operating reactors. This potential for enhanced safety makes nuclear power more attractive as an energy option. I propose to discuss the developments underway in industry, supported by the Department of Energy, and the safety evaluations being done by the Nuclear Regulatory Commission on the evolutionary and advanced reactor designs.

BACKGROUND

All but one of the licensed nuclear power plants operating in the United States today are light-water reactors of the pressurized or boiling-water type. Most of these have output ratings in the range of 800-1300 Mwe. Although these plants have proven to be safe, they nevertheless have experienced sufficient technical and economic problems to warrant review of some fundamental aspects of reactor design for the future. Accordingly, in the early 1980s various vendor, government, and utility organizations began to develop future reactor designs with improved safety. These improvements result from attempts to eliminate the problems and safety concerns uncovered by years of operating experience and also to provide simplified safety systems that are more reliable and potentially less expensive.

The Nuclear Regulatory Commission (NRC), recognizing the industry's efforts in developing future reactor designs, has also taken steps to establish a framework for licensing future designs and to help ensure that these designs achieve enhanced levels of safety over current generation designs. These steps include:

1. issuing severe-accident and advanced-reactor policy statements that state the Commission's safety expectations for future designs,
2. publishing a new rule that establishes requirements for certification of standardized reactor designs (10 CFR Part 52)—once approved by the NRC, the certified reactor designs would only require solution of site-specific issues to obtain a construction permit, and
3. initiating reviews of future reactor designs, including early interactions with designers to provide preliminary guidance at the conceptual design stage on the acceptability of these designs.

Although I mention these actions briefly, they are extremely important in preparing the way for a resurgence of the nuclear industry. In the remainder of this paper I will discuss the NRC's review of the safety aspects of these future designs.

DISCUSSION

The Commission considers future reactor designs to fall into three general categories. These are:

- evolutionary light water reactor (LWR) designs,
- advanced LWR designs, and
- advanced non-LWR designs.

Table 1 lists the reactor designs currently under development, by these categories. The table also indicates those designs that are presently under review at NRC.

Although the Commission, in its Advanced Reactor Policy Statement, stated that advanced designs should achieve a level of safety at least equivalent to current-generation reactors, it expects each of these three generations of reactor designs to achieve an enhanced level of safety over the previous generation. Specifically, the evolutionary LWRs should have enhanced safety characteristics over currently operating plants and the advanced designs should achieve an enhanced level of safety over the evolutionary designs.

Our review to date indicates that these designs are proposing to achieve an enhanced level of safety by application of the following:

Evolutionary LWRs

- Certification based on a full-scope, standardized design.
- Incorporation of lessons learned from previous operating experience (generic safety issues, TMI-2 fixes, etc.).
- Simplification of designs (separation and independence of safety system, etc.).
- Incorporation of design features to strengthen the prevention and mitigation of the dominant severe-accident sequences and phenomena.
- Completion of a full scope probabilistic risk assessment (PRA).
- Higher levels of safety system reliability that go beyond single failure.

Advanced Designs (LWR and non-LWR)

- Certification based on a full-scope, standardized design.
- Simplification of design and higher levels of safety system reliability through the use of passive safety systems.
- Greater emphasis on prevention of accidents that could lead to significant core damage.
- Reduced dependence on and vulnerability to operator actions.
- Smaller size (i.e., modular designs and fabrication techniques).
- Ability to demonstrate by test the performance of the plant under severe challenges.
- Completion of a full scope PRA.

The proposed designs do not include in every case all of the attributes listed. They also have many differences in concept and detail by comparison with reactors operating today. To make judgments on the

acceptability of these designs, the NRC must develop licensing requirements appropriate to each design. The development of these requirements is a task the Commission is now doing. It involves identification of the safety issues associated with the designs and deciding how to assess their safety. The latter item can be a complex task, particularly when the future designs propose a tradeoff of traditional safety features (such as containment and emergency planning) for greater core-damage prevention. Before describing some of the key safety aspects of the proposed future designs, I will briefly review the approach employed on the evolutionary and advanced designs, to illustrate how the Commission is addressing the development of the licensing requirements for future plants.

As mentioned earlier, the Commission intends to require that future plants achieve a level of safety at least equivalent to that of current-generation LWRs. To achieve this, the review of future plants has its roots in the approach, requirements and objectives developed to license current-generation plants. This includes maintaining a defense-in-depth safety approach, complying with the guidance in the Commission's Severe Accident Policy Statement (as codified by a recent rule on standard plant reviews) and providing reasonable assurance that future designs meet the objectives proposed by the staff for implementation of the Commission's Safety Goal Policy. Accordingly, for the future designs, the reviewing staff uses current rules and guidelines where practical; however, in many areas, additional guidance needs to be developed. Maintaining defense in depth is of primary importance in developing this guidance.

Defense in depth has been and remains a key component of the Commission's safety philosophy. It ensures that reactors are designed with appropriate attention to accident prevention, accident termination, accident mitigation, and emergency planning provisions. While defense in depth has been codified for current generation LWRs through NRC's rules and regulatory guidance, its application to future designs requires some new thinking as well as interpretation. The staff review approach will allow some flexibility in the application of defense in depth to future designs; however, it will not allow elimination of any one of its major components. For example, several advanced designs have proposed the elimination of offsite emergency planning based upon a projected low probability of a release of radioactive material. This would be in conflict with the defense-in-depth concept, and I think the elimination of offsite emergency planning would not be acceptable, however remote the need for it might be. Therefore, the staff is evaluating the appropriateness of changes in current emergency planning requirements to give credit to reactor designs with long transient response times and a reduced likelihood of release, while still maintaining equivalent protection to the public.

With respect to the Commission's Severe Accident and Safety Goal Policies, the staff has proposed that the requirements for future plants should be directed toward ensuring a core-damage frequency of no greater than 10^5/reactor year and a large-release frequency of no greater than 10^6/reactor year. To meet such objectives, improvements over current designs will likely be necessary. However, the staff will not judge the acceptability of future designs by means of a single or limited set of top-level goals such as comparison of PRA results to LWR PRA results or safety goals. Rather, the staff will identify those accident sequences and phenomena that the future designs need to address to have a reasonable chance of meeting the 10^5 and 10^6 objectives.

With this brief overview of the NRC safety-evaluation approach, let me now turn to some of the key safety aspects of the evolutionary and advanced designs. Both the evolutionary and advanced designs are pursuing standardization, simplification of safety systems, and enhanced safety. However, the ways in which this is being done differ from the evolutionary to the advanced designs.

Evolutionary LWR Designs

The evolutionary LWR designs have many safety features in common with the more recent designs operating today. However, they have attempted to improve on these designs by incorporating features that address particular problems uncovered as a result of operating experience (for example, locating BWR recirculation piping and pumps inside the reactor vessel). In addition, improvements have been

made to reduce the likehood of a core-melt accident so as to be able to meet the 10^{-5}/reactor-year core-damage objective. These include:

- separation, redundancy, diversity and independence of safety systems (emergency core cooling, residual heat removal, etc.) and their supporting systems (electric power), and
- reduced core power density.

These designs are also incorporating features to enhance mitigation of the effects of a core-melt accident, should one occur. These features are considered necessary to meet the objective of less than 10^{6}/reactor-year probability of a large release of radioactive material and are directed toward mitigating the more likely severe accident scenarios. Specifically, the evolutionary designs are adding:

- enhanced primary-system depressurization capability,
- hydrogen control measures,
- severe accident core debris cooling capability, and
- full primary pressure capability for fluid systems that interface with the primary system.

These features are directed toward enhancing the safety of the designs by improving upon and supplementing safety features found on existing reactor designs. The assessment of enhanced safety is thus fairly straightforward in these designs since no tradeoffs with traditional safety features are being proposed.

Advanced Designs

The advanced designs are placing an even greater emphasis on core-melt prevention than the evolutionary designs. For the advanced LWR designs, the key new features being proposed include a passive decay heat removal and emergency core-cooling capability. In addition, in the event of a core-melt accident, passive core-debris and containment heat removal capability are also provided. These are illustrated in Figure 1 for the advanced passive PWR and Figure 2 for the advanced passive BWR. These systems are to have the capability, without operator action or AC power, to respond to various loss-of-power and loss-of- coolant type accidents in a highly reliable fashion. Sufficient water inventory is to be provided to enable several days of passive cooling without additional water supplies being added. I have heard that the advanced LWR designs will propose changes in emergency planning as well as other design features, such as elimination of the auxiliary feedwater system, as credits for the features that improve accident prevention.

For the advanced non-LWR designs, passive decay heat and containment heat removal capability are also being provided. However, these designs propose to use the natural convection of air, instead of water to air, to remove decay heat as illustrated in Figure 3. The use of air cooling essentially allows indefinite heat removal without operator action or electric power. For such designs, the designers propose that core-melt accidents can be essentially eliminated from consideration. Specifically the MHTGR and PRISM developers propose to eliminate conventional containment structures and to eliminate emergency plans for

the nuclear plant sites. As in the case of advanced LWRs, the proposed changes would be credits for improved prevention.

Safety Perspective

To state it succinctly, advanced reactor designers are incorporating enhanced safety features that reduce the probability of core damage and prevent large releases of radioactive material. The designers have concentrated their efforts on prevention and have achieved commendable results. The new features have the potential result of safer plants, provided the performance of the features are demonstrated. Their acceptance by the NRC is still under review.

In the cases of proposed trade-off of the new features against long established design requirements, such as containment, fundamental questions arise at the core of the nuclear-plant safety philosophy that was established and evolved over a 40-year period. The potential changes have very large impact and implications for the future of nuclear power in the United States. Accordingly, the NRC is conducting a particularly thorough and careful review of such proposals. Although the developers are impatient to take the next steps, I think it most important that regulatory decisions on such features be studied and soundly based. Decisions of highest quality will serve the public and industry best.

It is now too soon for anyone to predict what decision the Commission will render on the question of a containment building for advanced reactors. However, I think I can comment on a number of the considerations in such a decision:

1. **Balance of prevention and mitigation.** In their quest to improve safety, developers have given highest priority to prevention, with evident results. I think more attention to mitigation is needed, because the new concepts lack the base of experience, however good they look in principle, to conclude that nothing can go wrong. A better balance is needed.

2. **Defense-in-depth.** Precisely because we do not know everything that could go wrong, fall-back positions and alternatives should be available to deal with unanticipated sequences that could lead to severe accidents. Who familiar with LWR mishaps could deny such a proposition?

   A corollary: independence of barriers is also important. To an extent, containments can function independently of the reactor, i.e., a change in the state of the reactor does not imply a change in the capability of the containment. If, as proposed in the MHTGR, the fuel particle coating is to be the containment, then the independence between reactor and containment disappears, and it is necessary to examine how changes in reactor state could affect containment—not only reactor transients, but also matters of fuel manufacture and quality assurance, fuel handling, etc.

3. **Prototype testing.** In the earlier days of reactor development it was possible to build and place into operation systems and components without prototype testing. It is true that models were often used as well as similarity arguments, i.e., the proposed component has similarity to a component that has been in service with a developed base of experience. I think that the environment today is more exciting and, in particular, that systems and components performing important safety functions should have prototype testing under design and expected conditions of operation.

4. **Severe accidents.** The Commission has made considerable progress in implementing its Severe Accident Policy for operating reactors over the last several years. Implementation of the Station Blackout Rule, the Individual Plant Examination Program, and the Containment Performance Improvement Program, of which BWR Mark I containments are the first to be decided, are the major steps of this

progress. There is not enough time to describe these in detail, but taken together, they move beyond the design-basis accidents to best- estimate performance of plants in severe accident conditions. I expect that trend to continue in the case of advanced reactors.

5. **Human factors.** As a consequence of Three Mile Island and Chernobyl, much attention has focused on human error and performance. Training has been improved, the person-machine interface has been improved, and much attention is now focused on accident management development, i.e., preparing operators to deal with and regain control of the situation in a severe accident. This, too, will be an important aspect of approval of advanced reactor concepts.

As a backdrop to these technical questions, there are a number of social and political considerations. Although the NRC decision process is, and should be, fundamentally technical, I believe we all—and industry especially—must understand the nature of this environment in which we all must function because ultimately, the public will decide whether the new technologies that are being developed will be used. These decisions will be made through Congress,

through state referenda, and through actions of public utility commissions and investors.

In closing, let me say that industry and government have embarked on tasks that hold the promise of safer nuclear power. However, there are many hurdles yet to overcome. The Commission encourages the work, and early licensing interactions on the evolutionary and advanced designs continue. Based upon our reviews to date we believe that these designs have the potential to achieve a level of safety beyond that achieved by currently operational LWRs, provided satisfactory resolution can be reached on the many issues remaining to be settled, including the acceptability of some fundamental changes in how to achieve enhanced reactor safety.

Table I

Evolutionary LWRs	Design	Size
-Advanced Boiling Water Reactor (ABWR)*	General Electric	1356 Mwe
-System 80+*	Combustion Engineering	1270 Mwe
-Standard Plant-90 (SP/90)*	Westinghouse	1350 Mwe
Advanced LWRs		
-Advanced Passive-600 (AP-600)*	Westinghouse	600 Mwe
-Simplified Boiling Water Reactor (SBWR)	General Electric	600 Mwe
-Safe Integral Reactor (SIR)	Combustion Engineering	320 Mwe
-Process Inherent Ultimate Safety (PIUS)	ASEA Brown Boveri	600 Mwe
Advanced Non-LWRs		
-Modular High-Temperature Gas-Cooled Reactor (MHTGR)*	General Atomic	137 Mwe per module
-Power Reactor Inherently Safe Module (PRISM)*	General Electric	138 Mwe per module
-CANDU-3	Atomic Energy of Canada Limited	450 Mwe

* Currently under NRC review

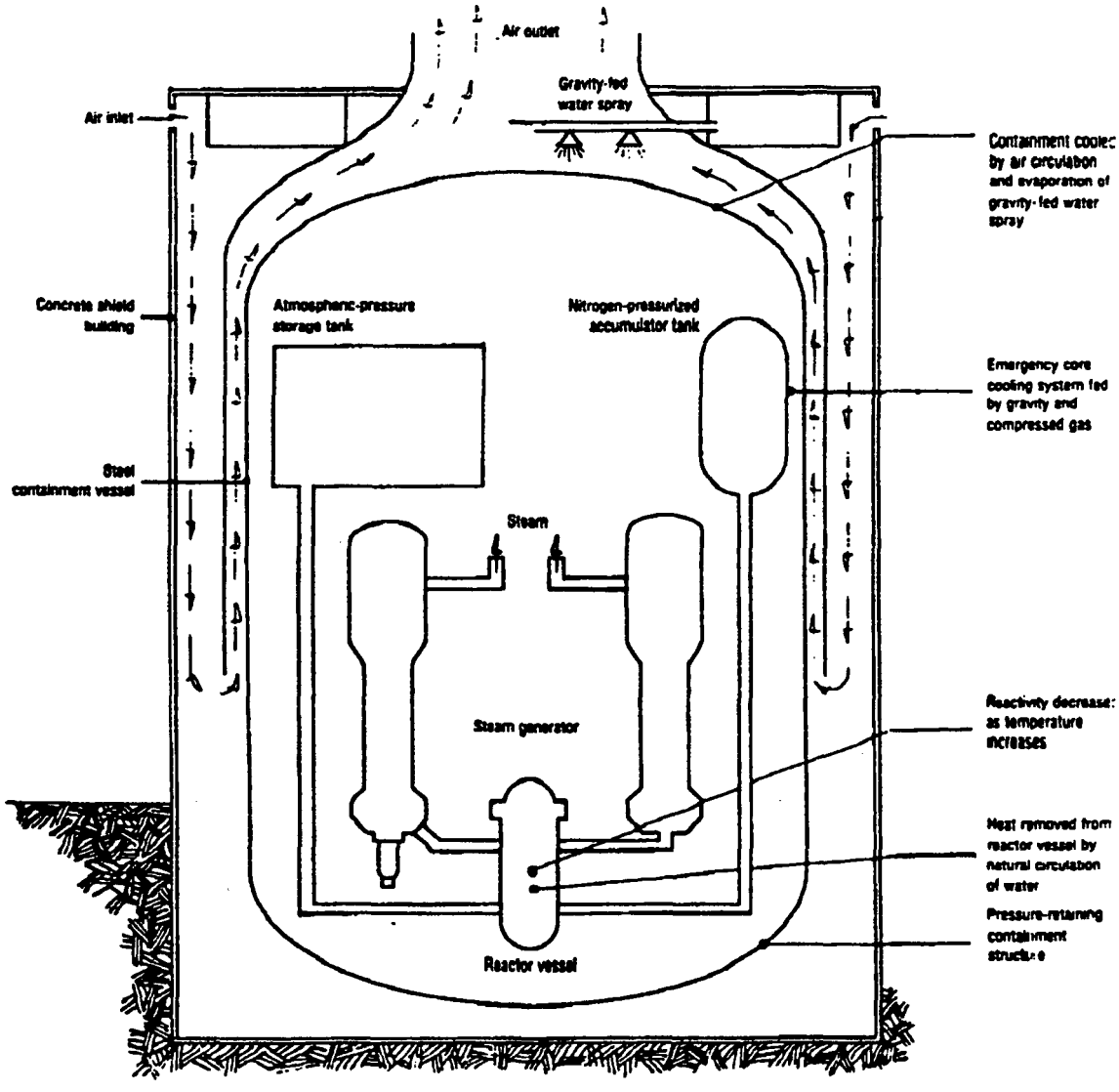


Fig. 1. Advanced passive light-water reactor.

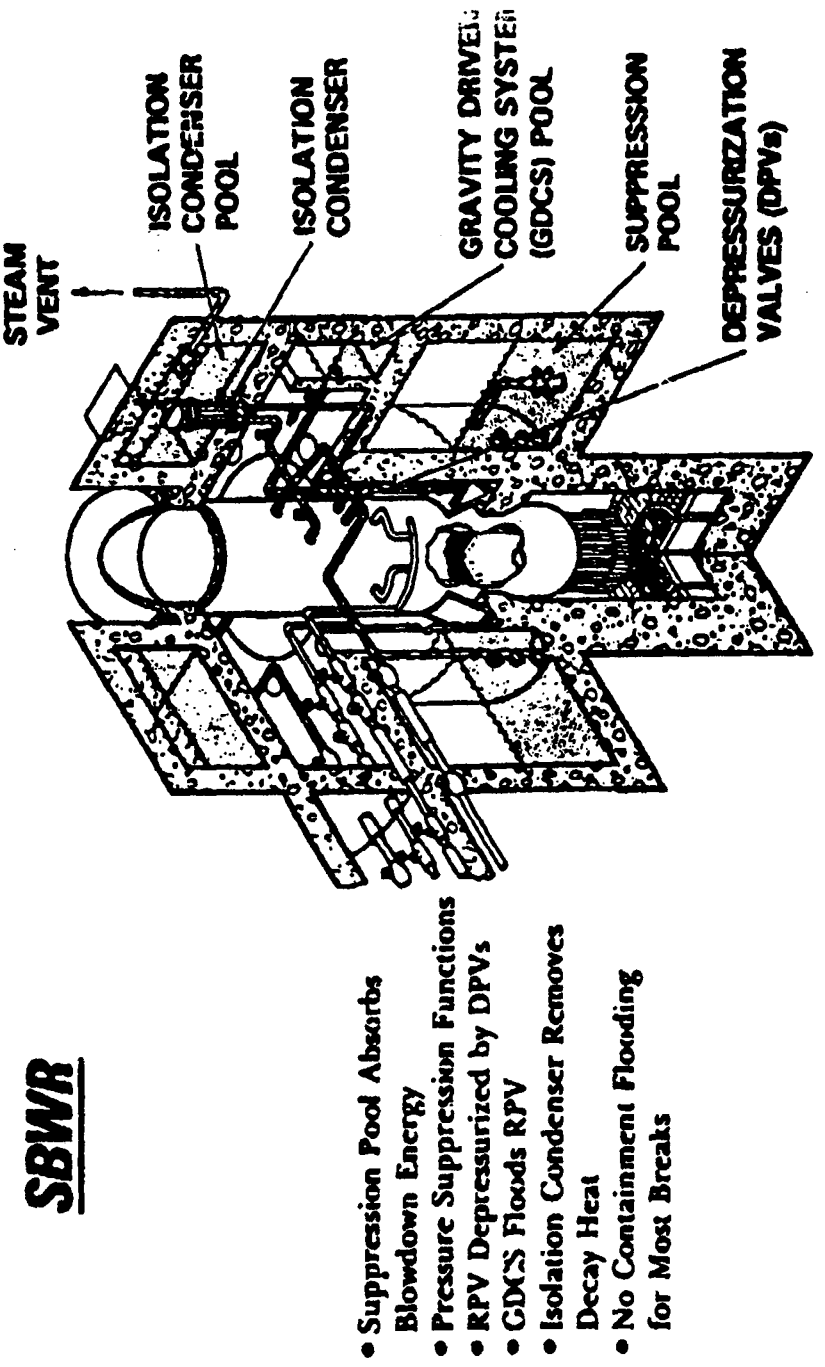

SBWR
STEAM VENT
ISOLATION CONDENSER POOL
ISOLATION CONDENSER
GRAVITY DRIVEN COOLING SYSTEM (GDCS) POOL
SUPPRESSION POOL
DEPRESSURIZATION VALVES (DPVs)
• Suppression Pool Absorbs Blowdown Energy
• Pressure Suppression Functions
• RPV Depressurized by DPVs
• GDCS Floods RPV
• Isolation Condenser Removes Decay Heat
• No Containment Flooding for Most Breaks

Fig. 2.

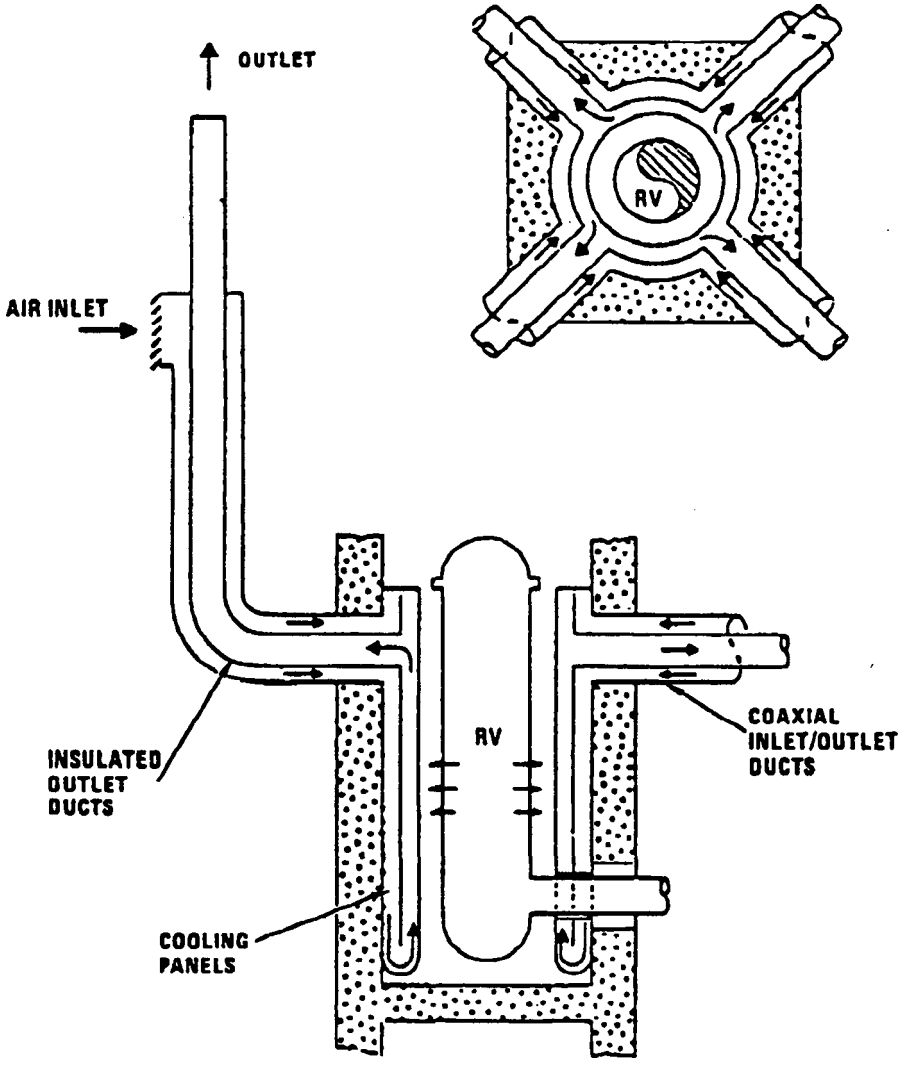


Fig. 3. Passive air-cooling.

INTERNATIONAL DISASTER RELIEF: OBSTACLES TO IMMEDIATE RESPONSE

by

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Because this session is devoted to the discussion of disaster response, I have been requested to give a brief overview of the problems generally encountered in the conduct of relief operations, nationally and internationally, as a result of either a man-made or natural disaster. Also, so that delegates will be familiar with the methods used by a major organization involved in international relief, I have been asked to give a briefing on how the International Red Cross was formulated and the system under which it conducts its global relief operations.

First, permit me to congratulate the leaders who assembled this unique and significant conference of leading scientists. The experts participating here have been instrumental in the development of technology benefiting mankind in scientific areas that a few years ago existed only in the wild imagination of science fiction writers. Great strides have been made in technological advancements that have contributed immensely to the improvement of living standards.

Regretfully, however, there is a negative aspect to certain elements of these developments. Of major concern is the threat to the environment and the pollution posed by possible accidents involving nuclear plants, hazardous chemical spills, and transport crashes, to name a few. Advances in technology have in some instances even created friction between governments, resulting in threats of conflicts.

Natural disasters have affected our planet throughout history and in recent times we tend to think that these catastrophes are on the increase. It is more likely, however, that because of the tremendous development of communications technology, disasters are identified and reported more systematically whenever and wherever they occur. These technological advances, coupled with the tremendous increase in world population, result in disasters affecting more people globally and seriously adding to the number of disaster relief operations yearly.

Disaster preparedness planning and training is crucial if relief assistance to victims involved is to be rendered immediately and efficiently. Unfortunately, a complacent attitude has existed in preparedness planning even though experience has shown that this complacency has caused serious delays and has cost thousands of lives. Preparedness is of extreme importance, and it is most gratifying that disaster response is given a priority in the deliberations in this conference.

To talk about international disaster response we must narrow down the discussion to organizations that are continuously involved in disaster relief. Although there are a large number of organizations that become involved in relief operations when a major disaster occurs, there are only a few that have disaster relief as an obligatory program in their corporate charter. Many organizations, therefore, do not have preparedness plans or staff training and become involved on an ad hoc basis, and with all good intentions, but in many cases they add to the problems already created by the disaster itself.

Invariably people will turn out in large numbers to volunteer help when a catastrophe occurs. Relief to victims involved is primarily delivered by volunteers, especially during the emergency phase immediately following the occurrence of a disaster. Here again, considerable confusion or costly delays in aid delivery can occur because of lack of trained leadership to properly coordinate this outpouring of good will.

Panic rarely is a major problem following disasters. Actually, stress situations in many instances brings out the best in individuals, and they perform in a manner far beyond what they thought themselves capable of. Psychologists can address this factor far better than I, but my guess is that it is related to the old axiom of how a reluctant mule can be started by use of the two by four syndrome. We all have it in us but need a good whack to get going.

The idea that if a victim loses everything he has, then, he can use anything you give him is a serious fallacy. This notion many times results in large contributions in kind that can be harmful to the victim's health or recovery. It also causes problems in logistical channels, which delay delivery of critically needed items of appropriate relief and ties up numbers of workers badly needed in the distribution system. Heavy, unnecessary costs are incurred, wasting funds badly needed for direct relief. Items such as food and medical supplies should not be shipped unless specifically requested by on-the-scene relief authorities. The same applies to personnel, regardless of their particular specialties or expertise.

Serious public relations problems have occurred when well-intentioned individuals or merchants offer to donate valuable, inappropriate items and, therefore, have to be refused.

Appeals are made for cash contributions and specifically needed items not available on the local market or obtainable from a reasonable distance from the disaster scene. Cash permits specifically needed items to be purchased locally at great savings and lower transport costs. Cash also fits local needs and is very helpful in restoring the local economy that, in most instances, was badly affected. Restoration of the local economy has a direct influence on the overall recovery of the victims and the area involved.

The political situation in countries sometimes cause delays in immediate response. Time will not permit a detailed discussion of this problem, but in most cases the lack of organization and preparedness planning by governments is a key factor that causes delays in both the emergency periods as well as the recovery and rebuilding phase of the disaster. Politics play a significant role, particularly in refugee operations.

So far I have only touched on a few of the obstacles that hamper the immediate response following a disaster (only the tip of the iceberg). I think that it would be somewhat clearer if I describe for you how disasters are handled by what is the world's largest and best known humanitarian organization, the International Red Cross.

First, a little background on the movement. In 1859, Henry Dunant, a Swiss businessman was horrified when he saw the thousands of dead and wounded left totally unattended following the battle of Solferino (Italy) between the allied forces of Italy and France against Austria. Dunant recruited volunteers from the surrounding villages, and for the first time in those early conflicts an organized relief effort was conducted. Dunant wrote a book upon his return to Geneva which described in detail his experiences in Solferino. He promoted the idea of forming neutral units in countries that would be trained to care for soldiers on both sides of a conflict. His book caught the attention of government leaders, who agreed to a meeting in Geneva in October 1863. Hence, the birth of the International Red Cross. The ideas formed during this and the meetings that followed led to the formation of the rules of war known as the Geneva Convention and subsequent protocols, and they were also the forerunner of the League of Nations and the present day United Nations.

Scanning the 125 years since this early beginning, we can see that the International Red Cross and Red Crescent movement today are made up of three component bodies:

(1) The International Committee of the Red Cross (ICRC),

(2) The League of Red Cross and Red Crescent Societies (League)

(3) All of the 149 National Red Cross and Red Crescent Societies throughout the world.

The International Committee of the Red Cross, the parent organization headquartered in Geneva, is responsible for the relief actions during *armed conflict* and *strife situations*; guardians of the Geneva Conventions and the recognized neutral body by governments around the world.

The League, established in 1919, is the world federation of which all Red Cross and Red Crescent societies are members. The League, headquartered in Geneva, coordinates *development programs and natural disaster relief actions* with all member societies throughout the world. All must adhere to the Fundamental Principles of the Red Cross and Red Crescent: Humanity, Impartiality, Neutrality, Independence, Voluntary Service, Unity, and Universality.

The national societies are chartered by their governments, recognized as politically neutral and most have responsibilities for disaster relief and other programs, such as First Aid, Blood, and many medical and welfare activities. Membership today totals around 260 000 000 volunteers and staff worldwide.

International conferences of all components of the Red Cross movement, also including high-level government representation, are held every four years to ensure worldwide agreements, recognition, and coordination, not only within the movement but by governments as well.

When a major natural catastrophe occurs in a country, the immediate response is the responsibility of the government of that country supported by the Red Cross/Red Crescent and other organizations capable of rendering relief. If these actions are to be immediate and efficient, proper preplanning and training is essential. The Red Cross/Red Crescent Society of the country involved immediately reports the disaster to the League with the most detailed information posibble, such as the extent of damage, number of people affected, number dead and injured, relief actions taken, etc. The society must also advise what is needed beyond its own resources. These needs must be listed in detail—quantity, specifications, and number and type of personnel if manpower is required to assist the society in meeting its relief responsibilities. Relief aid to victims generally include food, clothing, emergency shelter, and medical care.

Immediately upon receipt of this detailed information, the League relays the data in an appeal to its member societies and includes shipping instructions for relief supplies requested as well as a cost estimate of funds needed for the operations. Societies respond by return wire what they will contribute in response to the appeal.

This brief description, although incomplete, shows the critical need for preplanning and coordination that is absolutely necessary. The conduct of the operation always remains the responsibility of the affected society. In this system the actions emanate from inside the country with coordinated support by sister societies from the outside. The advantage to this operational approach is obvious.

Finally, as delegates to this conference, when addressing the actions needed to help victims of disasters, you should keep in mind that there are many organizations, both government and private, national and international (including the United Nations), that are already established to take action. What is needed is the deeper involvement and participation of the scientific community represented by delegates attending this meeting. I can assure you that you will be welcomed with open arms and it would certainly further the theme of this conference: "Technology-Based Confidence Building."

I hope the recommendations emanating from this conference will contribute greatly toward the improvement of disaster response, both nationally and internationally.

NUCLEAR POWER IN THE CONTEXT OF GLOBAL WARMING

by

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INTRODUCTION

The greenhouse effect has long been cited as an argument for nuclear power. Now that global warming has become a matter of broad public interest, it is appropriate to reexamine the extent to which nuclear power could help to ameliorate the greenhouse problem. It is of particular interest to do so now, because while concern over greenhouse warming has been increasing in recent years, confidence in the prospects of nuclear power has been waning.

These coupled topics suggest a succession of questions, to be explored below: How serious is the environmental threat posed by the greenhouse effect? How large a part do fossil fuels play in producing greenhouse gases? Is it possible to prevent or abate the anticipated global warming? Can nuclear power play a significant role? What overall approaches might best reduce greenhouse emissions?

THE PROBLEM OF GLOBAL WARMING

The greenhouse effect is caused by gases which absorb infrared radiation from the earth and thereby increase the earth's temperature. Independent of human action, there is already a sizable greenhouse effect due to the carbon dioxide, water vapor, and ozone naturally in the earth's atmosphere. Without this absorption, the mean surface temperature of the earth would be 255°K. Instead, it is 288°K.

The "greenhouse effect" of current interest arises from the increased concentrations of the greenhouse gases caused by human activities. The most important of these gases are carbon dioxide, methane, nitrous oxide, ozone, and a number of chlorofluorocarbons (CFCs).[1,2] If present trends continue, their buildup will cause an "effective CO_2 doubling" by some time in the middle of the next century. This is the time when the temperature rise will be the same as if the CO_2 concentration had reached 600 ppm (roughly twice the pre-industrial level) and the other gases played no role. The actual doubling date will depend upon production rates but it could come as soon as 2030. It will bring with it large environmental changes.

At effective doubling, the earth's equilibrium temperature is expected to rise by an average of roughly 4°C, but increases half as great or even twice as great cannot be excluded. Precipitation patterns will change and the sea level will rise, perhaps by several feet. Crops, forests, and animal species will experience unprecedentedly rapid changes in their local environment, and some are likely to have great difficulty in adjusting or even surviving.

The impacts will fall unevenly among countries. Perhaps the USSR or Canada will on balance be better off. Others may suffer moderately and still others, perhaps Bangladesh, could be devastated. There is no certainty as to the impacts. But if one waits until the environmental consequences are clearly visible one has waited too long, because the temperature rise lags the increase in atmospheric CO_2 concentrations by several decades due to the thermal inertia of the oceans.

Continuing to increase atmospheric concentrations of greenhouse gases constitutes a global environmental gamble of unprecedented magnitude. Although relatively benign outcomes are possible, serious impacts are probable, and widespread disaster is quite conceivable. The uncertainty can be used as an excuse for doing little or as an imperative for taking vigorous action. It depends where one places the burden of proof. On other environmental and health issues, there is growing caution. Before new products or processes are allowed, and even in some cases to allow the continuation of past practices, proof is demanded that the product or process be safe. Even slight risks are unacceptable. It would be totally at variance with this standard to be complacent about global warming on the grounds that firm proof of harm is lacking.

ROLE OF FOSSIL FUELS

It is commonly said that the expected temperature rise will be about one-half due to CO_2 and about one-half due to remaining greenhouse gases (see Table 1). However, this presumes that the production of CFCs and nitrous oxide will continue at high levels. There now appears to be a realistic prospect that CFC production will be curtailed and perhaps virtually eliminated within the next decade or two. The clean air measures proposed by President Bush in June 1989 raise the possibility that nitrous oxide emissions may also be reduced.

Further, it is important to distinguish between CO_2 per se and the overall role of fossil fuels. The fossil fuel use which produces CO_2 is also believed to be responsible for much of the increase in nitrous oxide concentrations and, indirectly, for part of the ozone increase in the troposphere. Methane, a particularly intractable greenhouse gas, comes largely from agricultural activities, but there is some component from gas flaring and coal mining. Overall, the fossil fuel fraction of the anticipated greenhouse temperature rise may be closer to 75% than to 50%, at least if one assumes prior success in reducing CFC emissions. The actual numbers are very uncertain, partly because relatively small changes in anthropogenic contributions can produce large fractional changes in the net fluxes into the atmosphere.

Fossil fuels provide most of the world's energy (see Fig. 1). In 1987, they accounted for about 88% of the world's commercial primary energy.[3] Oil is the largest source of energy (40%) and of CO_2 production (45%), although coal is a close second for CO_2 (39%). In view of the importance of fossil fuels as a source of energy and of energy to economic well being, it will be difficult to restrain fossil fuel use. Many of the key difficulties stem from the global nature of the problem:

- Many countries contribute to the production of CO_2 (see Table 2). The problem cannot be settled by restraint on the part of any one country alone.
- The use of energy is very unevenly distributed. The developing countries, with about 3/4 of the world's population, are responsible for only about 1/4 of the world's energy use [4] and of CO_2 production. Their per capita energy use, now averaging about 6% of the U.S. rate, will have to increase if their economies are to grow.
- If country A is restrained and country B is profligate, they share the burdens unequally and the benefits equally.
- Some countries, e.g. the Soviet Union or Canada, may perceive themselves to be net winners from global warming.
- It is easier for affluent countries to adjust their energy policies than it is for less-affluent countries.

This is a formidable set of obstacles. Nonetheless, if the major industrialized countries, especially the United States and the Soviet Union, could agree that it is important to curb CO_2 production, the fact that they are the chief producers means that they could have an important initial impact.

RESPONSES TO THE GREENHOUSE PROBLEM

Possible responses to the greenhouse effect fall into two broad categories: adaptation and abatement or "prevention." These are not conflicting approaches. There will almost certainly be some climatic impacts from the greenhouse effect over the next half century or century. Planned or not, society will adapt. Adaptation measures may include population movement, changes in agricultural practices, and the building of dikes. If the mildest scenarios are fulfilled, the adaptation may be quite painless. If the most burdensome ones are fulfilled, some countries, especially those which are now at the margin of survival, may have their societies destroyed.

The more successful the abatement efforts, the less painful will be the adaptation. It is unlikely we will reduce CO_2 production to levels so low that they will be "acceptable," and it is probably impossible to raise them so high as to make the earth uninhabitable. Instead we are faced with a continuum of CO_2 levels with a continuum of consequences, many bad. A working assumption is that the less the anthropogenic CO_2 buildup, the better. There is a wide array of possible abatement measures:

- Elimination at the source. There are designs to remove CO_2 from the stack gases of power plants and dispose of it in the oceans, but it is questionable if this is economically practical.
- Reforestation. Any steps taken will be helpful, but the world may be fortunate if it merely succeeds in balancing the trend towards net deforestation.
- Conservation. This has great untapped potential, but no matter how successful it is, massive energy supplies will still be needed.
- Switch to natural gas. This is a useful short term measure, because natural gas produces substantially less CO_2 per unit energy than does coal. However, it still is a producer. Further, the magnitude of ultimately available gas resources is a matter of unresolved debate.
- Nuclear power. If environmental and safety concerns are resolved, this could have a large impact for many decades. However, in most countries it would be necessary to overcome strong public reservations before there could be a major expansion of nuclear power, and even its continued use is in doubt in some countries.
- Solar power. To date, its main contributions have been from hydropower and biomass, but there are also hopeful prospects for solar photovoltaic power. It is not clear at what price and in what amounts solar power will be available.

Each of these approaches, with the possible exception of removal at the source, has merit, but none offers a convincing prospect of being sufficient by itself. Growing world population and growing economic aspirations imply growth in world energy demand, and it will be very difficult to avoid some increase in fossil fuel production. The question is, how much?

The problem calls for a combined response in which all constructive avenues are exploited, not a purist's response in which only the "ideal" solution is pursued. The most promising sustainable approaches to abatement are conservation, nuclear power, and solar power. These are sometimes viewed as being in

competition. But there is no danger of overkill, i.e., of achieving "excessive" reductions in CO_2 production. The different approaches are complementary, not competitive.

THE CURRENT STATUS OF NUCLEAR POWER

In this spirit, I will explore some of the issues related to the use of nuclear power, as *one* component of an abatement strategy. Nuclear power is now being produced commercially in 26 countries with somewhat over 400 reactors (see Table 3).[5,6,7] The leader, in terms of fraction of electricity derived from nuclear power, is France, where 70% of the electricity is nuclear. The worldwide nuclear share of electricity generation was about 17% in 1988,[6] and total nuclear generation was about 1800 billion kWhr. If this had been generated using coal, production of CO_2 would have been about 8% greater than was actually the case.

Total nuclear generation rose nine-fold in the 15 years since 1973, corresponding to an average annual rate of growth of 16%. It is clear that this growth rate will not continue during the next decade. The International Atomic Energy Agency has projected a worldwide growth rate until the year 2005 in the neighborhood of 4%, with even lower rates for North America and Western Europe.[8] The U.S. Department of Energy offers estimates which are even more conservative.[9] For the U.S., even in the highest case, the expected increase in nuclear generation is only 1% per year until 2005.

For the 2005 to 2020 period, the DOE report indicates a 4% annual rise as the "high reference" figure, but clearly this is not an absolute maximum. Given sufficient priority, considerably greater growth rates are achievable as illustrated by the history from 1973 to 1988.

The actual priority will depend on many factors, including assessments of the greenhouse effect and of the desirability of nuclear power. There have been a number of concerns about nuclear power, which have contributed to the current sluggishness of its development and which threaten its future in many countries. These include:

- Nuclear reactor safety. Three Mile Island and Chernobyl intensified existing fears.
- Nuclear waste disposal. There are no permanent disposal sites in operation in any country, and until there are proven workable sites not everyone will agree that the nuclear waste disposal dangers are small compared to the greenhouse dangers.
- Nuclear weapons proliferation. A world which makes wide use of nuclear power will be a world in which many countries have the technical base and some of the facilities to ease their development of nuclear weapons.
- Nuclear power is expensive. In the U.S., there are examples of essentially prohibitive costs for individual plants.
- Nuclear power cannot make much difference.

These concerns have been extensively discussed and debated in recent years, but the issues remain unresolved. In response to these concerns nuclear advocates argue that: (a) the safety record of nuclear reactors, the Chernobyl type aside, has been very good, and a next generation of reactors can be safer still; (b) with sufficient care in the packaging of nuclear wastes (or spent fuel) and with proper choice of site, disposal will pose negligible risks; (c) the *incremental* proliferation dangers from expanded use of nuclear power are less threatening than the dangers from the perceived "incentives" for military adventures which might come with energy shortages or disruptive climate changes; and (d) the example of France, and even

some examples from the United States, demonstrate that an efficient nuclear program can provide electricity which is less expensive than electricity from fossil fuels.

As of mid-1989, these arguments have not been persuasive enough to permit a resumption of a major nuclear expansion in the industrialized world. However, nuclear power may become relatively more acceptable to the public if there is convincing progress in addressing reactor safety and waste disposal issues,[10] and if the environmental and security dangers of heavy fossil fuel dependence loom larger. Rather than pursue these matters further, we turn to the last of the issues suggested above: can nuclear power make a significant difference? If the answer is positive, then the stakes become greater and it is all the more important to address the question of acceptability.

First, has nuclear power already made a difference? France provides a striking example of what can be accomplished given vigorous utilization of nuclear power. From 1973, the year of the first oil embargo, to 1986, French primary energy consumption rose 11%, while CO_2 emissions dropped 24% (see Table 4).[3,11] The CO_2 drop was primarily due to a substitution of nuclear power for oil and coal. As of 1986, 70% of the electricity in France came from nuclear power and 18% from hydroelectric power. Overall, France used about half as much total primary energy per capita as the U.S. and its per capita production of CO_2 was less than 1/4 that of the U.S. Even so, France has by no means exhausted the potential for CO_2 reduction, still deriving about 2/3 of its energy from fossil fuels.

For the full OECD (essentially, Western Europe, North America, and Japan), the record was qualitatively similar, but less dramatic. CO_2 emissions dropped 2% while primary energy consumption rose 7%. For the world as a whole the picture was less favorable. CO_2 emissions rose 21%, with large contributions from increased coal use in China, the United States and India and from a large increase in natural gas use in the USSR.

POTENTIAL FUTURE IMPACT OF NUCLEAR POWER

Could other countries repeat France's success? To understand the potential for reduction of CO_2 production in the U.S., we will consider how the 1988 U.S. energy economy might look if it were restructured with the overriding goal of reducing CO_2 emissions. We first consider the sources of 1988 U.S. CO_2 emissions (see Table 5).[7] The CO_2 came in roughly equal parts from: (1) electricity generation, mostly from coal (33%); (2) the residential, commercial, and industrial sectors, mostly from oil and gas (36%); and (3), the transportation sector, almost entirely from oil (31%).

Replacing the coal and oil used for electricity generation by nuclear or solar power would save 30% of the 1988 CO_2 production. The fossil fuels used in the residential, commercial, and industrial sectors are used primarily for heating and could largely be replaced by electricity. The all-electric home is common and it could become universal. Arbitrarily, we hypothesize the elimination of another 20% of 1988 CO_2 production by halving fossil fuel use in these sectors and making a partial switch from coal to natural gas. The largest remaining source of CO_2 is transportation. Here the most direct means of improvement is by increasing the fleet mileage of automobiles, although eventually mass transportation and electrified transportation could have further impacts.

Even with no gains from transportation, total U.S. CO_2 production would be halved with the changes suggested above. If the electricity were to all come from nuclear power, about 500 gigawatts of additional nuclear capacity would be required, but this would be achievable over, say, 35 years, given a national program to encourage nuclear power. To the extent that solar electricity proves to be economically practical,

the nuclear load would be eased. Over this same period, it is assumed that improvements in energy efficiency could make increases in U.S. primary energy consumption unnecessary, despite increases in population and gross national product.

The potential role of nuclear power has been deprecated with the assertion that replacing all U.S. fossil fuel generation of electricity with nuclear power would reduce global greenhouse emissions by only 4%.[12] It is easy to understand the origin of such a number: (a) the U.S. is responsible for 1/4 of the world's CO_2 production, (b) 1/2 the greenhouse effect is due to CO_2; and (c) electricity production is responsible for only 1/3 of CO_2 production. Thus, the gain would be $\frac{1}{4} \times \frac{1}{2} \times \frac{1}{3} = \frac{1}{24} = 0.04$.

However, what the U.S. does could be repeated elsewhere. Further, replacement of fossil fuels eliminates more than CO_2, and the fossil fuel "share" of greenhouse savings is probably closer to $\frac{3}{4}$ than to $\frac{1}{2}$. Finally, nuclear power not only can replace fossil fuels in electricity generation but can also fuel the replacement of fossil fuels by electricity in direct uses such as building and industrial heating. Together, these could reduce fossil fuel use by at least a factor of two. With these considerations, the share of greenhouse gas emissions which could be eliminated through global nuclear power expansion is in the neighborhood of $\frac{3}{4} \times \frac{1}{2} = \frac{3}{8} \approx 0.4$. This neglects the long term potential for the greater use of electricity in transportation.

World uranium resources are not a serious limitation. Affordable uranium resources (less than $0.007 (US 1987) per kWhr) are estimated to amount to about 30 million tonnes, which would suffice to supply roughly 6000 reactors over a 40-year lifetime.[13] More than one-half of the world's present primary energy could be supplied by 3000 reactors, which is an ambitious target for nuclear power in the foreseeable future. This means that if energy growth rates are restrained, the need for breeder reactors will not arise for many decades, giving time for their development, or for the development of possible alternatives including fusion power and extended uranium resources.

THE UTILITY OF GRADUAL AND DIVERSIFIED PROGRESS

It is important to remember that global warming is a long term problem. We cannot hope to solve the problem quickly. However, gradual changes could serve to reduce future greenhouse gas concentrations far below the levels anticipated in standard projections of future fossil fuel use. A first step would be to stop the present 1% or 2% annual growth in world CO_2 production. There are likely to be difficulties in achieving this, but with the example of France before us, it is not unreasonable to set such a target.

If, for example, the industrialized world were to reduce CO_2 production by 1% per year while the developing countries increased their production by 2%, CO_2 production would initially drop and would not return to its present level for about 20 years. The 1% per year decrease is a more modest drop than achieved by France from 1973 to 1986 and is half the decrease hypothesized above for the U.S., given substantial nuclear (or solar) expansion. Overall, 30 years would be bought, during which the cumulative CO_2 production would be no greater than if all the rates remained for 30 years at their present levels. The CO_2 outcome would be the same, but global inequities would be reduced, without severely exacerbating the greenhouse problems. Beyond 30 years or so, it is not possible to anticipate what technological and economic changes will occur.

An eclectic mix, in which diverse contributions are embraced, provides the best prospect of success and the greatest hedge against surprises and difficulties. The discussion here has emphasized nuclear power, but solar power and enhanced energy efficiency can play important roles, and forest management and natural gas utilization can also contribute, especially in the near term before major expansions of nuclear or solar

power could be accomplished. What is needed is an incremental approach, with contributions from many technologies.

Such an approach is also appropriate when one thinks of the other dimensions of the problem. In terms of time scale, unspectacular annual gains, sustained over several decades, can have spectacular cumulative effects. In terms of geography, it is important to have restraint in fossil fuel use in as many countries as possible.

Any additional gain is a gain, because the problem is continuous, not binary. There is no boundary to separate "acceptable" from "unacceptable" increases. For the present, prudence suggests that we assume that any increase in greenhouse gas concentrations is undesirable. The guiding principle should be to keep the production of these gases as low as reasonably achievable.

GLOBAL COOPERATIVENESS

Success in addressing the problem of global warming ultimately will require unprecedented international cooperation. An important initial task is to achieve a common scientific understanding of the issues. A prominent Russian scientist, not necessarily representative of the prevailing Soviet view, has termed attempts to reduce greenhouse gas production a "crime against humanity."[14] Gaining substantial scientific consensus is a minimal prerequisite for taking what may be costly measures.

At another level, the technological solutions to the myriad sub-problems—whether they be replacements for CFCs, more energy-efficient buildings and transportation, or cheaper solar cells—will be found more rapidly if there is cooperation between different national and multinational efforts. For nuclear power, key needs include a convincingly safe next generation of nuclear reactors, established methods and sites for nuclear waste disposal, and institutional and technological safeguards against diversion of nuclear materials for weapons use, either by nations or by terrorist groups. It is important to expand upon the already substantial international cooperation in these areas.

Given a scientific consensus and technical solutions, there may be a hope of developing international agreements to curtail CO_2 emissions. Many issues of equity will have to be resolved. If the USSR would be a net beneficiary from the warming of Siberia, what incentives or compensation should be given to restrain it from using its very large coal resources? If most countries conform to CO_2 emission standards, what sanctions could or should be taken to deal with remaining global polluters? How can local environmentalism, which puts primacy on the fears of people in the vicinity of nuclear sites, be replaced by a broader environmentalism which considers the global environmental implications of competing energy sources?

Finally, how can we address the disparate situations of the relatively affluent industrialized countries and the often-impoverished developing countries? It will be impossible to convince the developing countries to show restraint, if the industrialized countries are producing CO_2 at a ten times greater per capita rate. Even with the best intent, many of the developing countries will be unable to afford the luxury of coping with problems 20 years hence, given their immediate crises. For these countries, should the more affluent countries underwrite the development of solar power, nuclear power, and techniques for more efficient energy utilization? Will this be viewed as a purely charitable transfer of wealth, limited in scope for that reason, or as a means of self-preservation? Whose interests are served if we help China to replace coal by nuclear power?

Another form of parochialism, perhaps equally difficult to eliminate, is technological exclusiveness. For example, there is often an inverse correlation between individual assessments of the safety of nuclear power and assessments by the same individuals of the practicality of solar power. The technical issues are unrelated, correlated primarily by emotional allegiances or philosophical biases. What is needed is a technologically global spirit, in which proponents of one technology look with hopeful, albeit critical, openness at the status of putatively opposing technologies.

It used to be said, when the cold war was at its height, that an extra-terrestrial threat might persuade the US and the Soviet Union to resolve their differences. Perhaps the threat of global warming can help achieve an analogous lessening of local parochialism in the energy domain, whether the parochialism be based on national allegiances or technological allegiances.

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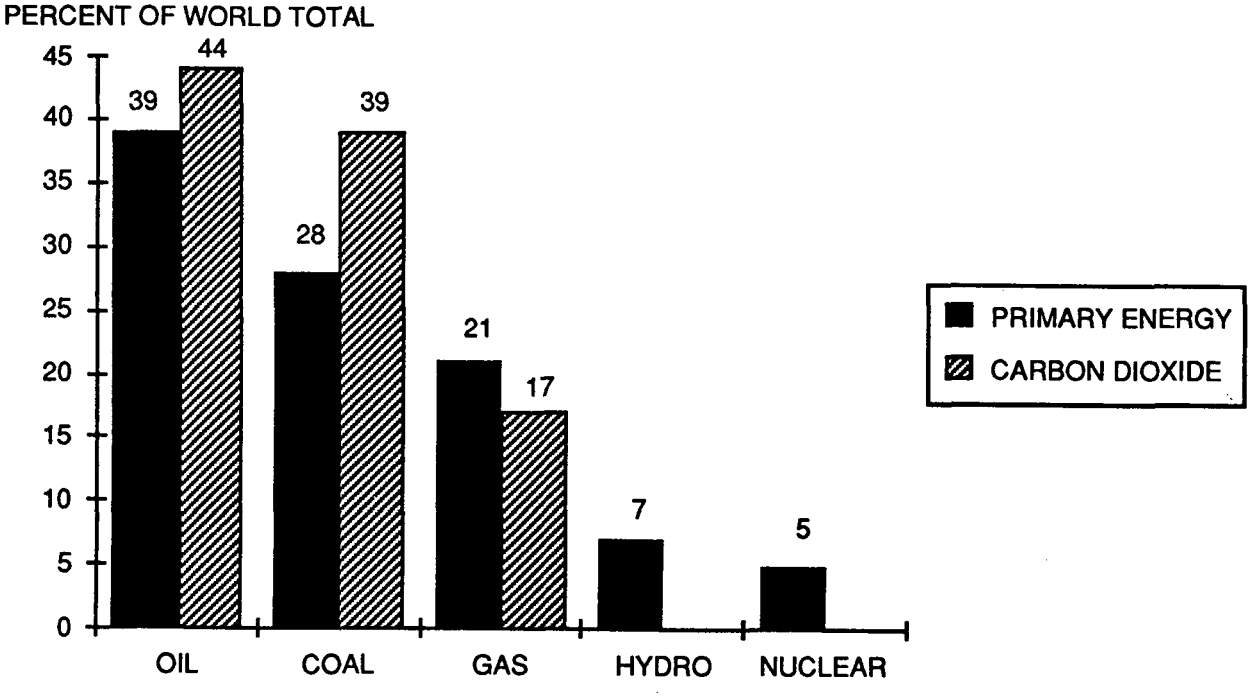


Fig. 1. Sources of world primary commercial energy supply and of carbon dioxide from fossil fuel combustion, in percent of world total (1987).

TABLE 1. Properties of main greenhouse gases.

Gas	Conc[a] 1985 (ppmv)	Incr[a] 75-85 %	Energy Fract[b] %	Radiative Sensitivity[c]
Carbon Dioxide	345	4.6	65 - 100[d]	10
Methane	1.7	11	32 ± 16	4 ± 1
Nitrous oxide	0.30	3.5	85 ± 20	2 ± 1
Ozone[e]	0.01-0.1			2 ± 1
CFC-11	0.0002	103	20 ± 10	2 ± 1
CFC-12	0.0004	101	5 ± 3	4 ± 1

[a]From Ramanathan.[1]
[b]Fraction of manmade contribution which is energy related, from ref. 2.
[c]Estimated relative contribution to temperature rise through mid 21st century. (normalized to CO_2), from ref. 2.
[d]Range reflects uncertainty as to magnitude of deforestation.
[e]Concentration refers to tropospheric ozone.

TABLE 2. World distribution of CO_2 emissions, 1986.[a,b]

Region	Carbon Released		
	Gigatonne	%	Cum %
United States	1.36	24	24
USSR	1.03	18	42
W. Europe	0.96	17	59
China	0.53	9	68
E. Europe	0.41	7	75
Japan	0.28	5	80
India	0.12	2	82
Canada	0.12	2	84
Other	0.94	16	100
WORLD	5.7	100	100

[a]Fuel use from ref. 3.
[b]CO_2 conversion factors from IEA/ORAU model, in megatonne C per exajoule: oil—19.2, gas—13.7, coal—23.8 (see, e.g., *Global Energy: Assessing the Future*, by J. Edmonds and J. M. Reilly (Oxford, New York, 1985), p. 243.

TABLE 3. World nuclear power use, 1988.[a]

Country	Capacity[b] Gwe	Generation[b] Gw-yr		Percent of Elec
	1988	1977	1988	1988
United States	101.3	30.2	63.3	19.5
France	54.8	2.0	31.4	70
USSR[c]	35.5	3.9	22.2	13
Japan	28.0	3.2	19.8	23
W. Germany	22.6	4.1	16.6	34
Canada	12.9	3.0	9.8	16
Sweden	10.1	2.3	7.9	47
United Kingdom	14.9	4.3	7.2	19
Spain	8.0	0.7	5.8	36
Belgium	5.7	1.4	4.9	66
South Korea	6.7	0.0	4.4	47
Taiwan	5.1	0.0	3.5	41
Others (14)	22.6	3.8	15.8	
WORLD	328	59	213	17

[a]Data from refs. 5-7.

[b]Gross generation and capacity are given.

[c]Generation data are extrapolated from 1987 for USSR and three other East European nations.

TABLE 4. Changes in energy consumption and CO_2 production: 1986 vs. 1973, by region.

	World[a]	OECD[b]	U.S.[b,c]	France[b]
1986 Energy Consumption (EJ)				
Oil	133.0	68.2	31.4	3.60
Coal	93.1	33.3	17.3	0.87
Gas	65.9	29.2	16.7	1.04
Nuclear	17.1	12.4	4.1	2.38
Other[d]		4.6	2.9	0.01
Hydroelectric	22.2	10.8	2.8	0.61
Elec. Imports		0.03	0.1	-0.09
Total	331.3	158.5	75.4	8.41
1973 Energy Consumption (EJ)				
Oil	130.6	78.9	33.9	5.21
Coal	66.0	27.2	13.0	1.22
Gas	45.7	29.0	22.0	0.58
Nuclear	2.3	1.8	0.8	0.14
Other[d]		2.6	1.6	0.01
Hydroelectric	14.3	8.4	2.6	0.45
Total	259.0	148.0	74.0	7.60
Change: 1986 vs. 1973 (%)				
Total energy consumption	28	7	2	11
Fossil fuel consumption	21	-3	-5	-21
CO_2 from fossil fuels	21	-2	-1	-24

[a] From U.S. DOE tabulations of world energy production.[3]

[b] From OECD tabulations of total energy requirements. [11]

[c] For purposes of comparison, OECD data are here used for the U.S. These differ from standard U.S. DOE summaries [3,7] by including biomass (which largely accounts for the increase from 1973 to 1986) and in using different parameters to calculate primary energy consumption.

[d] Includes miscellaneous solid fuels, e.g. peat, wood, and waste.

TABLE 5. Sources of CO_2 in U.S. energy budget, 1988 (in percent of total).[a,b]

	Percent from fuel			
Sector	Coal	Gas	Oil	Total
Residential/commercial	0	8	4	12
Industrial	5	8	12	25
Transportation	0	1	30	31
Electric Utilities	28	3	2	33
TOTAL	33	19	48	100

[a] Energy consumption data from ref. 7.

[b] CO_2 conversion factors same as in Table 2.

DECLINE IN ENERGY USE IN THE SEVENTIES AND EARLY EIGHTIES*

by

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ABSTRACT

The key to the decline in US energy consumption in the seventies and eighties lies in the US industrial sector. Changes in its output—both in quantity and product mix—led to large decreases in energy use, which have persisted to the end of the present decade. Energy saving through improvements in efficiency in the industrial sector, over and above those associated with normal capital stock turnover, appear to be much smaller than those associated with change in the output of the sector. Some of these changes were evident before the rise in the price of fuels in the seventies, but most were set in motion by the price increases. Energy-intensive industries have continued to decline, and import reliance on their products has increased. This is tantamount to importing energy, in the form of products, with no expression in tallies of annual US energy use. By contrast, conservation in other end-use sectors has shown a strong price elasticity.

INTRODUCTION

Total energy use in the United States departed substantially from post-World War II trends following the 1973 embargo; however growth in the consumption of energy resumed at near historical rates despite large increases in the price of all fossil fuels until the end of that decade (Figure 1). The gross national product (GNP) increased during this period at a faster rate than energy use. It came as a surprise to many forecasters that the second price shock in 1979-1980 associated with interruption in oil supplies (Iranian-Iraqi war) had such a profound effect on energy use. A decline persisted until early 1987. It is the purpose of this paper to address the ways in which the energy decline was accomplished.

By all analyses the decline in energy use was accomplished through conservation in all end-use sectors. By conservation in this context is meant a combination of voluntary and involuntary curtailment in use as well as more efficient conversion of resources into work and useful products. Because future energy shortfalls are predicted to lie on the horizon and because environmental concerns especially related to the air and atmosphere are increasing in both governmental and private sectors, there has been a call to make renewed efforts to deal with the upturn in energy use by promoting additional conservation measures throughout the economy. From the observation that "we use no more energy in the US today, and less oil than we did in 1972 despite an economy that is 46% larger,"[1] the argument that is made is 'we saw it work before, and let us regain the momentum that we seem to have lost, and in any event, it makes good sense.' However, the argument for the efficacy of conservation is not as straightforward as it seems if one looks

* Work performed under the auspices of the US Department of Energy by the Lawrence Livermore National Laboratory under contract W-7405-ENG-48.

closely at the national economy and at how the energy decline in the late seventies and early eighties was accomplished.

It is important and difficult to apportion exactly the role that greater efficiency and curtailment in use, whether voluntary or involuntary, made in the late seventies and early eighties, but it is desirable to look at the record of the period and attempt a general assessment.

THE RELATION TO GROSS NATIONAL PRODUCT

In examining this issue, the usual starting point is the GNP, since it is in principle a measure of the health of the industrial, commercial, agricultural, etc. sectors of the nation. It has shown a steady increase during the last two decades with a slowdown in 1981-2 when crude oil prices were at all time highs (Figure 2).

The fact that energy consumption per unit of GNP (Figure 3) nevertheless declined has been interpreted as direct evidence that lowered energy demand through improved efficiencies accompanied the growth in GNP.

Nonetheless it has been recognized that factors other than conservation are at work in reducing the amount of energy used to produce a unit of GNP. One factor has to do with the change in the make-up of the GNP from one dominated by resource development, industrial output and energy-intensive products to one dominated by services and less energy intensive activities, e.g., banking, insurance, health services, real estate, etc. The crossover occurred in 1975 (Figure 4), and the difference in the contributions of these two general categories to the GNP has continued to grow. As the US labor force in industry has fallen by the same percentage as the services have grown, the phenomenon is sometimes described as "deindustrialization;" however, such trends are also evident in other industrialized nations, such as Japan and West Germany,[2] and relate to a large degree of mechanization throughout the world. Support for this thesis is the fact that labor productivity (gross domestic product per work-hour in constant dollars) has climbed steadily in the US for more than a century.

Another factor influencing both the energy/GNP relation and the total amount of energy used in the period under discussion is change in the volume and character of industrial output. These changes are reflected in the total amount of energy used (Figure 1) by that sector as well as in the industrial sector's contribution to the GNP, which has remained relatively constant.

ENERGY USE IN INDUSTRY

The industrial sector is made up of manufacturing, mining, construction, agriculture, fishing and forestry activities. Manufacturing consumes approximately 80% of industrial energy and in 1986, contributed 68% to the industrial GNP in constant 1982 dollars. Mining is the next largest component. It consumes about 11% of the energy used in the industrial sector and comprises 10% of the industrial GNP. Construction and agriculture each consume between 6 and 7% of the energy and comprise 14 and 8%, respectively, of the industrial GNP.[3,4]

A detailed, up-to-date study of energy use in the many components of the industrial sector has not been made since 1983;[3] however, the large manufacturing component has been studied to 1985, the year preceding the collapse of oil prices.[5] Individual industries, such as steel within the group of primary metals

(manufacturing), have been independently examined. In the case of steel, energy use accounted for 7% of industrial primary energy consumption in 1986—down from 14% in 1973.[6] As in the larger, more diverse industrial sector, energy used for manufacturing has not grown at the same rate as total energy consumption in the US. Its principal energyconsuming components are shown in Figure 5. Manufacturing of bulk materials such as refinery products, glass, cement and clay products, pulp and paper, industrial chemicals and primary metals is approximately ten times as energy-intensive as the rest of manufacturing.[7] To understand the relatively small growth in industrial energy use over the past decade it is worthwhile to look at production in its energy-intensive components.

INDUSTRIAL PRODUCTIVITY

Conventional measures of productivity are the indices published monthly and annually by the Federal Reserve Board.[8] They are indexed to the year 1977, which is set at 100. Through 1988 the industrial production index increased to 137, manufacturing to 143 and mining to 104. The index is compiled from output expressed in physical quantities, production-worker hours and electrical power used, the former making up about 55% of the index. Judging from the production indices, lower industrial energy use would not appear to be related to decline in production; however, a close look at energy-intensive sectors within, for example, the manufacturing sector suggests that output has in fact declined. Figure 6 shows examples of production decline in primary metals, an energy-intensive sector within manufacturing. Production decline is estimated to account for 63% of the reduction in energy use between 1973 and 1986 in the steel industry[6] (Figure 6).

Figure 7 contains other examples: paper and paperboard production, cement production, auto sales as an example of metals fabrication, uranium production as representative of the mining industry, nitrogenous fertilizer production within the chemicals subsector of manufacturing, and petroleum refining. It is clear that any decline in output in these examples, or other energy intensive components of the industrial sector not shown here, has expression in total energy consumed by that sector (Figure 1).

INCREASED IMPORT RELIANCE ON INDUSTRIAL PRODUCTS

Appropriate import reliance for the various commodities is given at the bottom of the individual figures. Trends are clearly upward, which is tantamount to importing the energy embodied in the commodity. Increased import reliance can be a reflection on declining domestic production of that commodity coupled with stable demand and/or increased demand alone. In some instances, e.g., the steel industry (Figure 6), increased import reliance accompanied a decline in both domestic production and demand that started before the fuel crises of the seventies. For most of the examples shown in Figure 6 and 7, a notable increase in imports accompanied or followed production decline associated with the high fuel prices of the 1980-1 period. Other factors contributing to declining output and profitability include labor disputes and outdated equipment.

Apparent consumption of the commodities also fell; however, subsequent recovery in demand for cement, aluminum and copper was not accompanied by a comparable increase in domestic production and did not alter the generally upward trend in imports.

It is not possible in the space available to treat the numerous contributing factors to the production declines illustrated here. Each industry was subject to a unique set of pressures; nevertheless, high-energy

costs were a factor in most. For example, the automobile industry was impacted by changes in regulations, e.g., corporate average fuel economy (CAFE) and emission standards, by new behavioral patterns as well as by the consequences of high prices of fuel on both its operations and its market. The combined effect resulted in increased penetration by foreign products. Of the 10.3 million passenger cars sold in 1987, 3.2 million were of foreign origin.

THE ROLE OF EFFICIENCY

It appears that decreases in the industrial output contributed importantly to reduction in energy use during the 1979-1986 period. Not only did the volume of standard, energy-intensive products decline, but a new slate of less energy-intensive products became part of the industrial make-up of the country and contributed to the growth of GNP. What then was the role of efficiency in the reduction in energy use? It probably cannot be known precisely; however, some estimates have been made. Oak Ridge National Laboratory[9] has estimated that the level of annual energy use at the end of the 1973-1980 period was about 20 quads below what it would have been had the price shocks of the seventies not occurred, i.e., 76 rather than 96 quads in 1980. About half (10 quads) was attributed to reductions in the industrial sector and one-third (7 quads) in the residential/commercial area and the remainder, about 17% (3 quads) in transportation. Efficiency in the industrial sector, as distinct from other forms of conservation and other reasons for decreased use of energy, was estimated by Oak Ridge to account for 5 of the 10 quads. For the 1972-81 period the US Office of Technology Assessment (OTA) suggested that improved efficiency accounted for 3.4 out of 10.4 quads of the decline in industrial.[3] Of the 3.4 quads, about 2.3 quads is attributed to historical trends associated with capacity expansion and capital stock turnover and the remaining 1.1 quads to accelerated efficiency gains associated with higher energy prices. In the five or six years between 1980-1981 and the 1986 break in fuel prices, the total energy use in the country fell to 70.5 quads and recovered in 1986 to 74 quads. Thus, decline in gross industrial energy use (3-4 quads) over the same period (1980/1981-1986) more than accounts for the total national reduction of 3.5 quads. According to the OTA and Oak Ridge analyses, it appears that, at most, half, or 1-2 quads, of the 3-4 quad decline in the industrial sector can be attributed to improved efficiencies either as a result of normal industrial development or price incentives. The other half of the decline is related to changes in product slates and curtailment of energy-intensive industrial activities.

Conservation in all of its forms (improved efficiency and voluntary and involuntary curtailment) was operative in other end-use sectors throughout the period under discussion. There can be little question that it was largely driven by the high prices of most fuels but especially that of oil (Figure 8). Conservation has been called the nation's most important new energy source since 1973.[10]

Improved efficiencies contributed to the total decline in energy use in nonindustrial sectors (residential/commercial and transportation sectors) (Figure 8); however, the rebound in demand following the fall in prices in 1986 suggests that price elasticity was more important than irreversible improvements in efficiency. There probably was less incentive for investment in energy-saving improvements on the part of nonindustrial groups since the time horizon for expected return on investment is considerably shorter for individuals and small businesses than large industries.

The transportation sector has been subject to partial regulation by imposition of the CAFE standards on manufacturers of new passenger cars starting in 1978. Although nominal mileage standards have mandated fleet averages to improve from 18 to 26.5 miles per gallon in 1989, the effect on total consumption in that sector has been compensated by increased demand. The annual consumption of transportation fuels began

climbing again in 1984, i.e., before prices had started to decline substantially and presumably at a time when the accumulated effect of the CAFE standards should have become evident. Although the mandated mileage improvements are large, the average mileage recorded by the highway fleet (autos, trucks, buses and motorcycles) has not shown a comparable improvement. Between 1978 and 1987 the average mileage of the highway fleet increased approximately 3 miles per gallon—from 12.4 to 15.1 miles per gallon.[11] The explanation lies in the slower than anticipated turn-over in vehicle stock, the decreasing importance of fuel prices on total operating costs, which has influenced new vehicle purchases, and the rising preference for types of vehicles with lower average mileage (small trucks, vans, so-called "off highway vehicles," etc.).

CONCLUSIONS

Declining energy use in the industrial sector contributed substantially to overall decline in US energy consumption in the past two decades. To some small degree it was related to accelerated technological efficiency improvements, but largely it was related to a change in quantity and nature of domestic industrial products. The role efficiency played in other end-use sectors is largely unknown, but judging from the vigorous rebound in demand following the 1986 fall in oil prices, it appears to have been smaller than initially estimated. Furthermore, to some extent we are deceiving ourselves as to our total national energy consumption if we exclude increasing importation of energy-intensive products that we formerly produced domestically.

Conservation in the broad sense can contribute to the control of growth of US energy consumption, but it is questionable whether "technological fixes" leading to increased efficiencies in fuel use will be adequate by themselves. If conservation is promoted by high energy prices, it may involve further changes in US industry resulting in even greater importation of the energy-intensive products. It has been said "...the real danger is that a deception about the success of energy conservation (important though it is) could mislead our R&D planners in a period when these planners should be preparing acceptable supply technologies for another energy growth surge."[12]

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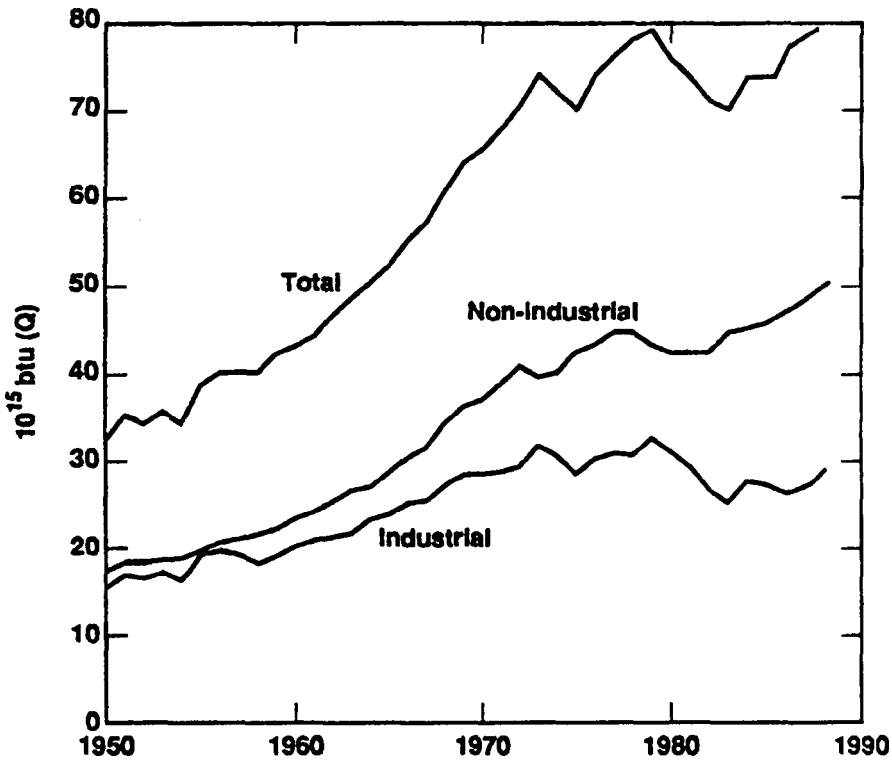


Figure 1. US Energy Consumption (Source: *Annual Energy Review, 1988* DOE/EIA-0384 (88) Table 4).

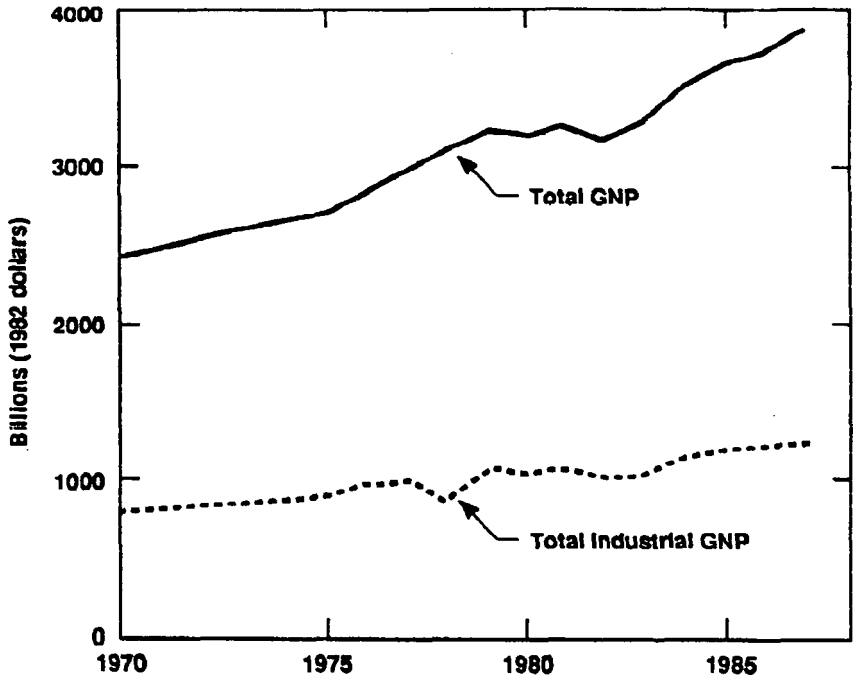


Figure 2. Industry's Contribution to GNP (Source: *Statistical Abstract of the United States 1981-1989*, US Department of Commerce, Bureau of the Census).

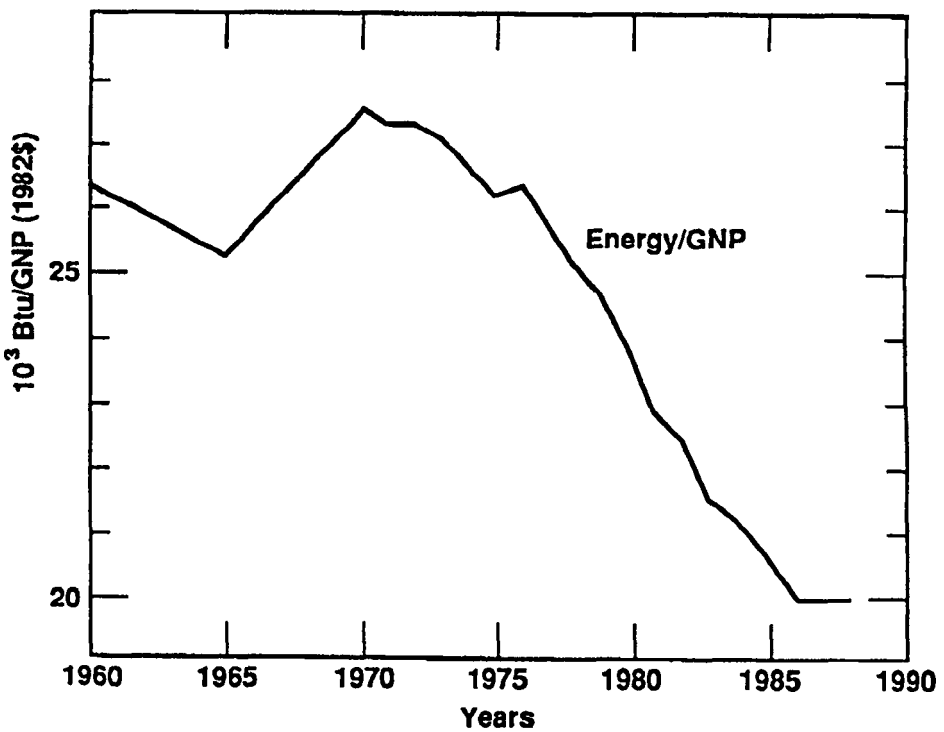


Figure 3. Decline in Amount of Energy Consumed to Produce a Unit of GNP (Source: *Annual Energy Review 1988*, DOE/EIA-0384(88) Table 8).

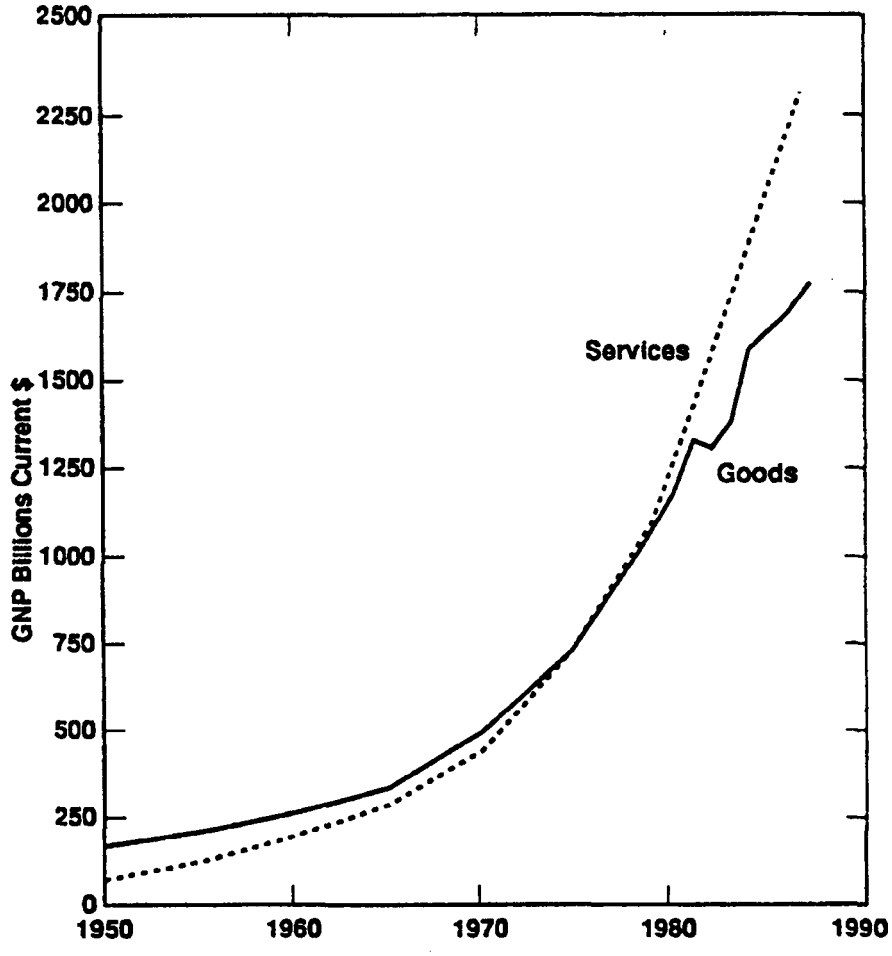


Figure 4. Contribution of Services and Goods to GNP (Source: *Statistical Abstract of the United States 1988, 1989*, US Department of Commerce, Bureau of the Census).

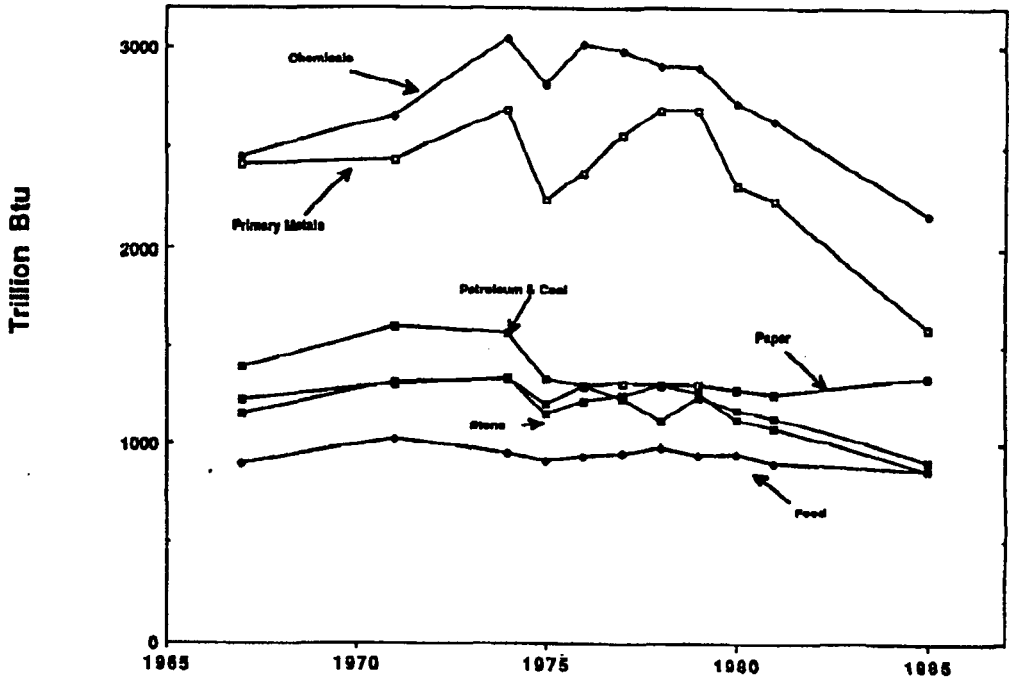


Figure 5. Energy Use in Manufacturing (exclusive of use of by-products and self-generation) (Source: *Statistical Abstract of the United States 1980-1984*, US Department of Commerce, Bureau of the Census; *Manufacturing Energy Consumption Survey: Consumption of Energy 1985*, DOE/EIA-0512(85)).

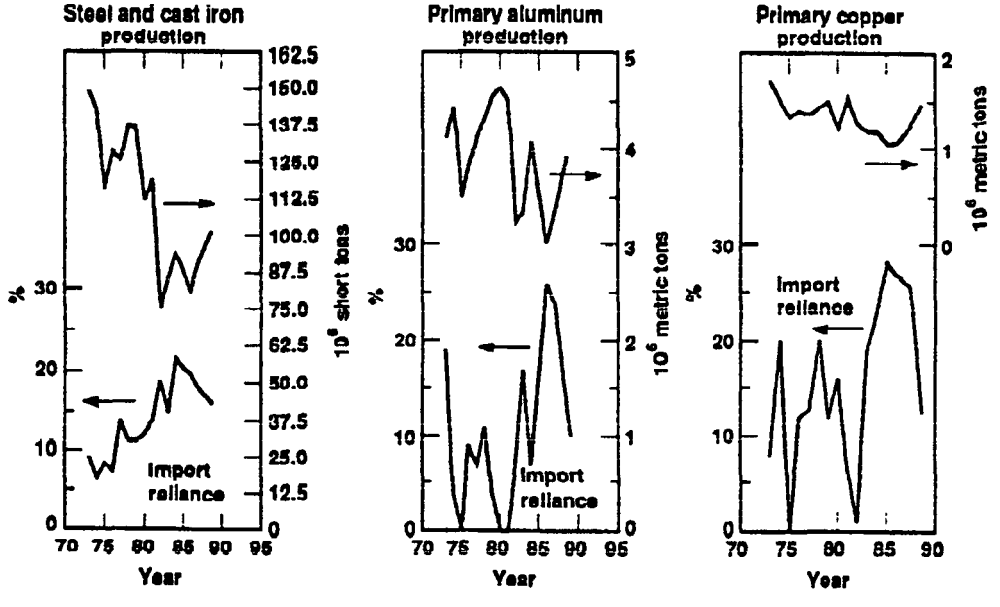
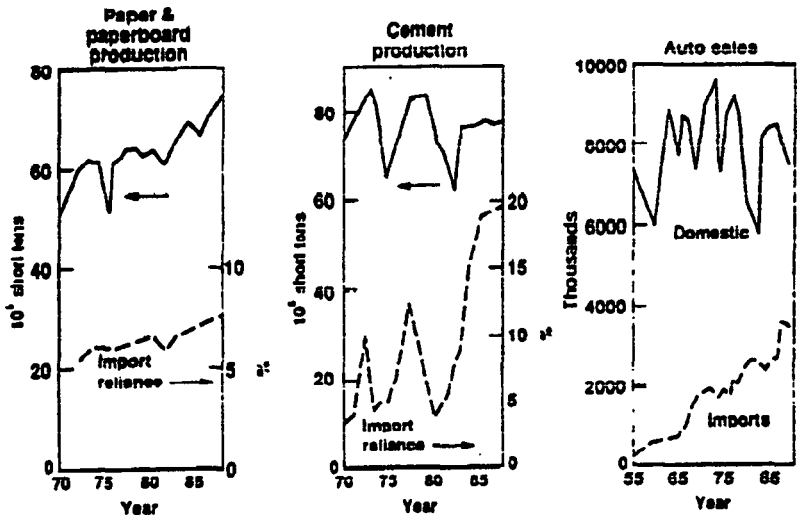
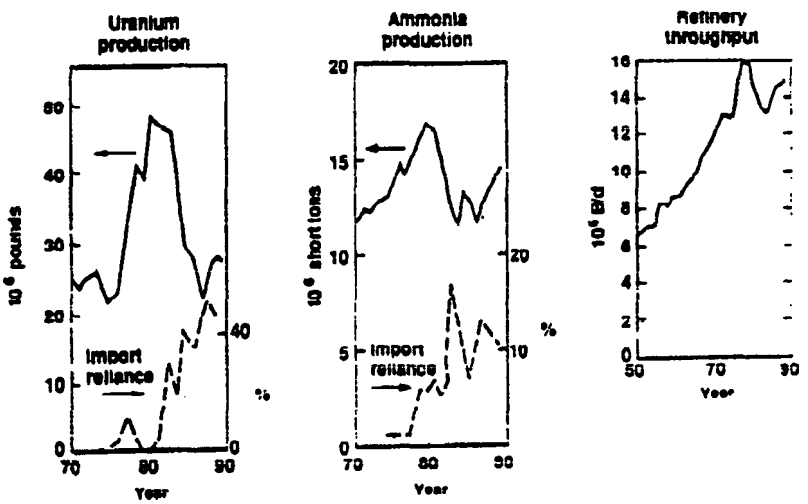


Figure 6. Production and Import Reliance for Three Primary Metals (manufacturing sector) (Source: *Mineral Commodity Summaries 1978, 1982, 1985, 1989*, US Department of the Interior, Bureau of Mines).



Source: Paper: Statistical Abstract of the United States 1974-1989, U.S. Department of Commerce, Bureau of the Census
Cement: Mineral Commodity Summaries 1978, 1982, 1985, 1989, U.S. Department of the Interior, Bureau of Mines
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Source: Uranium: Annual Energy Review 1988, DOE/E1A-0384(88) T. 96
Fixed Nitrogen: Mineral Commodity Summaries 1978, 1982, 1985, 1989 U.S. Department of the Interior, Bureau of the Mines
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Figure 7. Production and Import Reliance for Components of the Industrial Sector (Sources: Paper: *Statistical Abstract of the United States 1974-1989*, US Department of Commerce, Bureau of the Census; Cement: *Mineral Commodity Summaries 1978, 1982, 1985, 1989*, US Department of the Interior, Bureau of Mines; Auto: *Statistical Abstract of the United States 1989*, ibid; Uranium: *Annual Energy Review 1988*, DOE/E1A-0384(88) T. 96; Fixed Nitrogen: *Mineral Commodity Summaries 1978, 1982, 1985, 1989*, US Department of the Interior, Bureau of the Mines; Refinery Throughput: *Annual Energy Review 1988*, DOE/E1A-0385(88) T. 55.

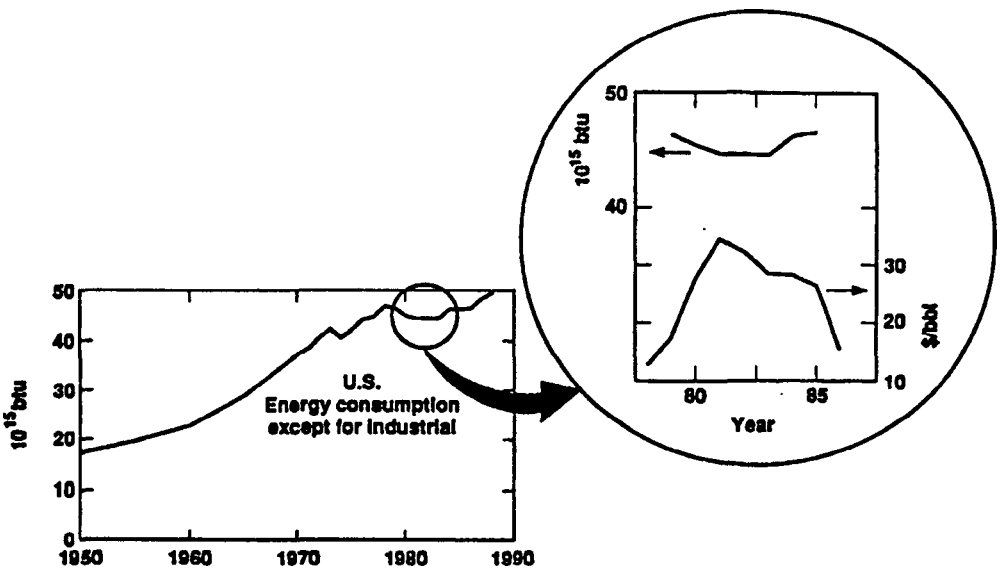


Figure 8. Response of Residential/Commercial and Transportation Sectors to Change in Price of Crude Oil (average US refiner's acquisition cost in current dollars.) (Source: *Annual Energy Review 1988*, DOE/E1A-0385(88), Table 4 and Table 65).

FROM MILITARISM TO ENVIRONMENTALISM: A NEW FOCUS FOR U.S.-SOVIET RELATIONS

by

Congressman George E. Brown, Jr.

Good morning. I appreciate the opportunity to share my remarks at the beginning of what looks like a very exciting and ambitious conference. I regret that I will not be able to stay beyond this afternoon to participate in the thought-provoking and productive discussions that I am sure will take place during the next four days.

For those who have been involved in promoting U.S.-Soviet scientific cooperation over the years, these are exciting times. As with essentially all other areas of U.S.-Soviet relations, the prospects for bilateral scientific cooperation have never appeared brighter. Over the past few years, the number of collaborative science efforts between the superpowers has increased dramatically. This parallels the overall increase in U.S.-Soviet exchanges spurred in large part by the 1985 and 1987 Reagan-Gorbachev summit meetings.

One of the fundamental assumptions underlying U.S.-Soviet scientific cooperation has been that such efforts can help contribute to improved relations between the superpowers. Since science is inherently an international discipline, and because scientists from any given field converse in a similar language, so to speak, U.S.-Soviet cooperative efforts have been viewed by many as a potential leavening agent for political relations between the superpowers. The other driving motivation for U.S.- Soviet scientific cooperation has been to achieve mutual advancement in our understanding of scientific and technical areas. As Dr. Frank Press, President of the National Academy of Sciences, explained in testimony to Congress a few years ago:

> The U.S.S.R. has the largest science and engineering manpower pool of any nation, and in many areas of science and technology Soviet accomplishments are at the forefront... [For this reason] we cannot afford not to cooperate with the U.S.S.R. in scientific research activities.

As it has turned out, U.S.-Soviet scientific cooperation over the past three decades has not proven to be a very significant force in helping ease tensions between the superpowers. Rather, the rise and fall of U.S.-Soviet bilateral exchanges as a whole have served more as a barometer of political relations between our two nations than as any form of climate control system. The rise in the number of exchanges during the period of detente, their precipitous decline following the Soviet invasion of Afghanistan, and their subsequent increase during the Gorbachev era have demonstrated that it is difficult to divorce the level of U.S.-Soviet contact from the overall state of U.S.-Soviet political affairs. And when the condition of these relations is poor, then the mutual benefits that might be achieved through cooperative efforts are simply lost.

What makes the present situation different, however, is that U.S.-Soviet relations are on a trajectory unlike any experienced during the past 40 years. Indeed, if the superpowers continue along their current path of military disengagement, economic interaction, and political dialogue, then there is every reason to believe that the degree and intensity of U.S.-Soviet contact across the board will reach levels that even a few short years ago would have seemed completely unfathomable, if not delusionary.

While we all recognize that the current trend of improved relations between the superpowers could be derailed by any number of potential developments, we should not let these possibilities serve as reasons for holding back from an aggressive agenda of U.S.-Soviet cooperation, not only in science and technology but across the full spectrum of areas in which we have mutual interests. Indeed, from my perspective, cooperative U.S.-Soviet efforts in the specific areas to be addressed by this conference—energy and environmental protection—could play a pivotal role in helping achieve a substantial redefinition of the U.S.-Soviet relationship during the post-Cold War period.

The redefinition that is needed should focus on the concept of mutual security rather than individual national security, and this concept should be incorporated into our negotiations to achieve sharp reductions in conventional and nuclear forces.

Although the concept of mutual security in terms of military relationships would represent a revolutionary change in attitudes for countries around the world that have been locked for generations in hostile competition, even this concept pales in significance to the shift in thinking that is really needed, which is to a new ethic of global security for the human race—a security measured not merely in military terms but also in terms of sustainable strategies for dealing with global energy and environmental problems.

I do not feel that it is unrealistic to believe that efforts to confront global environmental threats could become a fundamental defining character of relations between the superpowers, in much the same way that their relations over the past 40 years have been characterized largely by their military efforts. Moreover, it is not unreasonable to assume that a change in U.S.-Soviet relations of this sort—away from militarism and toward joint efforts at environmental protection—could result in the institutionalization of U.S.-Soviet scientific cooperation in a way that has been fundamentally impossible during the Cold War years.

The revolutionary developments currently underway in the Soviet Union make such a change conceivable. Many of you in this audience have been involved in U.S.-Soviet exchange programs over the past 30 years, and have thus witnessed firsthand the breathtaking changes now underway in Soviet society. In recent testimony before the Senate Foreign Relations Committee, George Kennan characterized these historic changes in his usually perceptive fashion. In Kennan's words:

> What we are witnessing today in Russia is the break-up of much, if not all, of the system of power by which that country has been held together and governed since 1917... Whatever reasons there may once have been for regarding the Soviet Union primarily as a possible, if not probable, military opponent, the time for that sort of thing has clearly passed.

This is quite a statement, coming from the author of the U.S. strategy of Soviet containment. Having visited the Soviet Union several times myself over the past three years, I share Kennan's view. I believe that in both perception and reality, there is no question but that the military threat posed by the Soviet Union to the Western Alliance has diminished during the Gorbachev era. I also believe that the forces of reform that have been unleashed by General Secretary Gorbachev are irreversible, which means that—barring an act of stupidity by the military or intelligence communities of either nation—U.S.-Soviet relations will continue to improve and the prospects for military confrontation will shrink even further.

This will happen largely because the Soviet Union, in an effort to boost its lagging economy, has no real option but to continue to seek relief from the expense of the arms race. As a result, we have every reason to expect considerable progress in arms control during the coming years. With sufficient political will, the superpowers should be able to enact agreements over the coming decade or two that reduce

their conventional and strategic military forces to a fraction of current levels, while maintaining more than sufficient nuclear capacity to ensure a robust nuclear deterrent.

As relations between the superpowers continue to improve, concern about the threat of nuclear war will diminish further, as will support for large annual defense budgets. In the Soviet Union, as in the United States, the public feels that too much money is being spent on defense and not enough is going toward domestic priorities. According to recent opinion polls in the U.S., 63 percent of the public feels that we are spending too much on defense, while more than 50 percent of American voters now see the Soviet Union as a minor threat to the United States, or as essentially no threat at all.

In contrast, nearly 80 percent of the American public feels that environmental pollution has become a major hazard to the nation and that further environmental protection is necessary "regardless of cost." Similarly, environmental problems have rapidly emerged as among the greatest national concerns in the Soviet Union. It appears from this information that both the American and Soviet people recognize that global environmental problems may present a greater long-term threat to the future of our nation than does the prospect of nuclear war.

In my opinion, this view is probably correct. Although there remains no match for the destructive capacity of a nuclear bomb, the risk posed by nuclear weapons seems increasingly manageable, whereas the risks posed by global climate change, ozone depletion, population growth, and widespread pollution seem increasingly unmanageable. Seen another way, although it is becoming easier to envision 40 or 60 years going by without another nuclear weapon being detonated on a civilian population, it is getting increasingly difficult to envision that same period of time passing without millions of people being affected adversely by global environmental problems.

This view squares well with the one that emerges upon reviewing comparable recent reports on the threat posed to the United States by Soviet military forces, on the one hand, and by global environmental problems, on the other. For a recent military threat assessment, one can turn to the unclassified version of the Joint Chiefs of Staff 1989 Joint Military Net Assessment, issued last month by the Pentagon. That document, in noticeable contrast with previous editions, conveys a resounding message that the prospect of nuclear war with the Soviet Union has become extremely remote. Reflecting this view, Admiral William Crowe, Chairman of the Joint Chiefs of Staff, recently remarked that he did not consider the Soviet Union to be his enemy. This statement by our nation's top military official stands as remarkable testimony to the changing perceptions of the Soviet threat.

For a recent environmental threat assessment, one can turn to a report called Global Environmental Change, issued jointly last fall by the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine. "The future welfare of human society is to an unknown degree at risk," according to the report. The source of this risk, the document explains, is human activities that are changing the global environment. This change is of such serious dimensions that prompt action is needed to guard against the possibility of an "irreversible experiment with our planet." To some extent, the authors claim, "We are already irrevocably committed to major global change in the years ahead ... regardless of our actions." Frank Press, Robert White, and Samuel Thier—Presidents of the three institutions that sponsored the report—conclude the document by saying: "We believe that global environmental change may well be the most pressing issue of the next century."

This is strong wording. Indeed, one might find such language analogous to the words used in military threat assessments issued during the height of the Cold War. However, the urgency and alarm conveyed in the document Global Environmental Change can hardly be considered ill-founded. By any rational analysis, global environmental problems confront us with challenges that rival any we have faced during the past 40

years of Cold War between the superpowers. Let me elaborate just briefly on this threat, and then I will discuss appropriate responses.

The most ominous environmental problem confronting us is that of global warming, caused by a build-up in the atmosphere of "greenhouse gases." According to the climate model of the National Academy of Science, the build-up of these gases will lead to an increase of between 2 degrees and 9 degrees Fahrenheit in global mean temperatures by the year 2050. If these estimates prove correct, then the rate of climate change over the next 60 years might be 10 times greater than the fastest known sustained climate change during the last 10,000 years.

Warmer temperatures would cause a melting of the polar ice caps and an accompanying rise in ocean levels. Ocean levels would rise one meter by the year 2050, according to some estimates. This would submerge up to 15 percent of Egypt's arable land, displacing more than 8 million people. More than 10 million citizens of Bangladesh would lose their homes and livelihoods, while much of the Maldives—a country comprised of nearly 1,200 islands barely two meters above sea level—would be inundated. According to a 1989 report by the Worldwatch Institute, a one-meter rise in ocean levels could create more than 50 million environmental refugees—more than triple the current number of refugees worldwide.

A warming climate would cause drastic changes in precipitation patterns and would also cause a major shift northward of existing agricultural belts. By some estimates, America's agricultural heartland could become a dustbowl, while Canada and the Soviet Union could become global suppliers of wheat. Some predict a dramatic increase in turbulent monsoons and hurricanes, whereas others anticipate the extinction of scores of species unable to survive in the altered climatic conditions. The entire economic balance of nations could be changed by shifts in growing seasons caused by a warmer planet. Such changes, in addition to those caused by rising sea levels, could have drastic repercussions on world demographics.

Ozone depletion poses no less of a problem, raising the possibility of millions of additional cases of skin cancer in America alone through the end of the next century. Nor can one treat lightly the problem of acid deposition, which is damaging forests and killing lakes throughout North America and Europe. These and other urgent environmental problems are global in character—irreverent of national boundaries. As such, they demand an international response. In my view, that response should rival the effort undertaken by the United States and the Soviet Union over the past 40 years to develop and deploy their current nuclear arsenals and worldwide military capabilities.

In Manhattan Project style, we need a crash program to develop alternative energy sources that would enable drastic reductions in the worldwide use of fossil fuels. This is the only way that we will achieve substantial reductions in the global release of carbon dioxide, while at the same time ensuring continued economic expansion. Solar, wind, and geothermal energy need to be tapped in the most effective and efficient ways possible. Fusion, nuclear fission, and hydrogen fuel may all offer important contributions to a more environmentally sustainable energy mix.

Energy efficiency throughout our industrial economy needs to be enhanced, whether through advanced materials development, superconductivity, architectural design, improved appliance design, or new manufacturing techniques. Substitutes for CFCs need to be developed and marketed as soon as possible, and biotechnology should be pursued aggressively for potential contributions to hazardous waste digestion and genetically altered plant hybrids that are resistant to pests and thus do not require such heavy applications of pesticides.

To help guide us through the development of these technologies we should adopt a national ethic of "technological stewardship," defined by an effort to develop technologies aimed at helping ensure the

sustainability of our planet for the indefinite future. We also need a complete reappraisal of our concepts of national security.

For the better part of this century, the threat of communism has been the most constant, unifying, and mobilizing force in U.S. foreign affairs. Our national security strategies have been defined almost exclusively in terms of weapons and military contingencies to deal with Soviet expansionism. However, as communism as a political, military, and economic system fails worldwide, it is becoming essential for us to develop a new, more comprehensive approach to our security strategies. Included in any such effort must be a recognition of the importance of ecological security and of the reality that the security of all nations is becoming inextricably linked.

As our national preoccupation with the communist threat subsides, we should shift a greater share of energy and resources to addressing the most pressing threat before us today: global environmental change. As part of this shift in focus, the institutions created to respond to the threat of communism will need to be scaled back proportionately, redirected to deal with new threats and national problems, or be dismantled entirely.

As for our national weapons labs—including Los Alamos and Lawrence Livermore—these will continue to play important roles in helping maintain our nuclear deterrent in an era of improved U.S.-Soviet relations and reduced strategic forces, but the missions of these organizations need to be diversified to include major efforts at helping confront environmental problems. Our weapons labs represent a unique national resource, and I would hate to see them lose their relevance in the world. This will happen, however, if their overriding focus remains the continued study, design, and development of nuclear weapons. Although it is true that there remain considerable uncertainties about nuclear weapons effects, there will come a day—if it has not already arrived—when we will have narrowed these uncertainties as much as we need to and when the national interests will dictate a redirection of the enormously qualified scientists involved in that task to the challenge of tackling other scientific uncertainties.

It is my view that the national weapons labs should play a major role in helping reduce the uncertainties facing us in the area of global climate change. Although the weapons labs already are doing some work in this field, a much greater level of activity should be encouraged.

One of our biggest priorities in dealing with the problem of global warming is developing a better understanding of the precise relationships between the Earth's climate, the oceans, the biosphere, and the geochemical cycles of all the major nutrients. The Global Change program being spearheaded by NASA is aimed at helping achieve this understanding, through the launch and operation of an array of space-based sensors during the 1990s. These satellite sensors, however, will generate an absolute torrent of data—on the order of 10^{12} bits every day, which is comparable to one Library of Congress daily.

Making sense out of that data will be a monumental and vital task if we hope to formulate policies in response to identified changes in the global environment. It is already clear that virtually all of NASA's space-science information systems would be needed to stay on top of the enormous data stream coming down from the Global Change satellites. One would think that Los Alamos and Lawrence Livermore could contribute substantially to helping tackle this problem. These labs are among the world's leading computational centers, with some of the nation's most extensive experience in large-scale computations, massively paralleled processing, computer networking and ultra-high-speed graphics. These capabilities have been established through the laboratories' extensive analyses of the physical phenomena associated with nuclear detonations. As daunting as such analyses have been, they dwarf in comparison to the task we face in developing a comprehensive understanding of planet Earth as an integrated system that is being disrupted on a worldwide scale by human activities.

Commenting on the enormous uncertainties that exist in our current understanding of global environmental change, one of the nation's leading climate modelers, Dr. Syukoro Manabe, has said that the capacity of an entire supercomputer would be needed to develop a realistic working model for one tree. Yet we are faced with the challenge of trying to model the global atmospheric impact of tropical deforestation taking place at a rate equivalent to the size of a football field every second.

The national weapons labs, and the nation's other centers of scientific and technological excellence, need to be mobilized to help us understand and respond to global environmental change. Achieving such a mobilization will not come easy, for it will require some concerted soul searching on the part of individual researchers, laboratory managers, and national policymakers who have been accustomed to thinking of national security only in terms of weapons systems and military spending. However, with concern about the risk of nuclear war descending, and concern about the global environment ascending, I am reasonably optimistic that the sort of transformation I am suggesting will take place.

My hope is that this conference helps forge such a path. If the U.S. moves vigorously to establish an aggressive national response to global environmental problems, then the result will be an exponential increase in contacts among scientists around the world—for the problems we are dealing with will demand it. I encourage you to think boldly during the next few days and to come up with creative new proposals for expanding the level of international scientific and technological cooperation aimed at the problems of energy development and environmental protection.

NONLINEARITY AND CHAOS: THE CHALLENGES AND LIMITATIONS OF MATHEMATICAL MODELING OF ENVIRONMENTAL AND SOCIO-POLITICAL ISSUES

by

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ABSTRACT

We discuss the extent to which recent improvements in our understanding of inherently nonlinear phenomena present challenges to the use of mathematical models in the analysis of environmental and socio-political issues. In particular, we demonstrate that the "deterministic chaos" present in many nonlinear systems can impose fundamental limitations on our ability to predict behavior even when precisely defined mathematical models exist. Since our primary aim is didactic, we make no attempt to treat realistic models for complex issues but rather introduce a sequence of simple models which illustrate the increasingly complicated behavior that can arise when the nonlinearity is properly taken into account. We begin with the familiar elementary model of population growth originally due to Malthus and indicate how the incorporation of nonlinear effects alters dramatically the expected dynamics of the populations. We then discuss two models which are caricatures of two issues—weather prediction and strategic/economic competition—of considerable importance to the general problem of technology-based confidence building. For certain ranges of their parameters, these models exhibit "deterministic chaos," and we discuss how this behavior limits our ability to anticipate and predict the outcomes of various situations. Finally, we close with a few remarks on our general theme, stressing that despite its limitations and because of its challenges mathematical modeling of complex environmental and socio-political issues is crucial to any efforts to use technology to enhance international stability and cooperation.

I. INTRODUCTION

In a conference on "Technology-Based Confidence Building" it is natural to ask what contribution one of the fundamental "technologies" of modern science—namely, mathematical modeling, typically including extensive computer simulations—can bring to global efforts to enhance stability and cooperation. A moment's consideration makes clear that the potential contribution is profound: for instance, one can immediately identify a number of environmental issues—the "greenhouse" effect, ozone depletion, nuclear winter—of overwhelming international concern in which an accurate quantitative understanding of the causal relationships between specific local actions and global consequences can only be obtained from studies of highly sophisticated mathematical models containing many subtle and counterbalancing effects. The situation becomes even more complex in the modeling of socio-political issues—for example, economic consequences of exchange rate or stock market fluctuations, third-world debt, combatting the AIDS

epidemic—when in addition to the complex technical issues one must try to account for the vagaries of human psychology.

Each of these issues involves many individual components, interacting with each other in complicated ways. Clearly one immediate, primarily technical, challenge to mathematical modeling is to quantify these interactions; for instance, in the "greenhouse" issue, to understand quantitatively the role of the Brazilian rain forest in helping to stabilize the amount of carbon dioxide in the atmosphere. Such technical questions will—and should—remain the purview of experts, and in some cases the resolution of these questions requires the successful collaboration of experts from many different disciplines. In this area, the challenge is to develop well-defined models, properly reflecting the essential features of the problems; for this technical challenge, the appropriate caveat is perhaps best captured by the famous shibboleth beloved of computer hackers: "garbage in, garbage out."

Beyond this problem-specific technical challenge, however, are challenges and limitations that arise from the very nature of systems in which many elements, some of which may adapt their behavior in time, are interacting. Such "adaptive complex systems" often behave in ways that seem unintuitive—or even counter-intuitive—based on everyday experience. For instance, the inherently nonlinear nature of these systems means that they can exhibit sudden and dramatic changes in the form of their behavior when small changes are made in the parameters describing the interactions within the system. Further, "emergent properties"—that is, characteristics whose existence is not at all apparent in the initial formulation of the system—frequently arise, and theories of "self-organization" in natural systems [24] have attempted to analyze certain aspects of this behavior.

While non-experts can hardly expect—nor be expected—to be aware of the subtle details surrounding the technical modeling of specific aspects of these complex issues, it is vital that in particular those responsible for making decisions on possible courses of action be aware of this second category of general constraints and characteristics that affect the applicability and reliability of the models. To achieve this awareness, it is essential to go beyond our conventional "linear" intuition and to develop an appreciation of what can—as well as what cannot—occur in complex adaptive systems. The development of the appropriate "nonlinear intuition" is extremely important, for it is clear that mathematical models, to the extent that they are credible, not only tell us what is likely to occur but *can limit our perceptions of what can occur.* Indeed, in our later discussion of the history of models of population growth, we shall exemplify this (potentially negative) aspect of modeling.

Our main goal in the present article is to assist in the development of this nonlinear mathematical "literacy"—or, in the current parlance, "numeracy" [27]—by describing and illustrating a few of the general challenges to and the limitations of mathematical modeling that arise from the complex, interacting, "nonlinear" nature of environmental and socio-political issues. Our perspective is based on the considerable recent progress that has been made in understanding nonlinear phenomena in the natural sciences [see, e.g., [7]. In particular, the surge of interest in nonlinear dynamical systems theory has shown that such concepts as "bifurcations", "attractors", "basins of attraction", "deterministic chaos", and "fractals" are essential for understanding the possible consequences of nonlinearity. In the following article we shall try to introduce, primarily by example, most of these concepts. For definiteness and in recognition of the our own limitations (particularly of time and space) we shall focus on two of the most important of these concepts: (1) "bifurcations"; and (2) "deterministic chaos".

"Bifurcations", which are sudden (sometimes dramatic), qualitative changes in behavior of a system in response to small changes in the parameters, are likely to be familiar to many of our readers, primarily because many of aspects of this phenomenon were discussed in the 1960s under the (perhaps overly

perjorative) rubric of "catastrophe theory" [51]. Its relevance to the modeling of complex environmental issues is immediate: indeed, the primary concern associated with the "greenhouse" effect is that slight changes in the concentration of atmospheric carbon dioxide leading to a slight change in the average global temperature—perhaps a small as a degree or two Celsius—could lead to catastrophic changes in the climate, inducing a man-made Ice Age.

In contrast, the phenomenon of "deterministic chaos,", has only more recently begun to work its way into public awareness [21]; thus much popularization remains to be done before its full significance is appreciated. As indicated above, the essence of this phenomenon is that even in systems whose evolution from moment to moment follows precise deterministic laws, with no external random influences of any kind, the behavior over long times can be essentially unpredictable and in fact as random as a coin toss. That a system governed by deterministic laws can exhibit effectively random behavior runs directly counter to our normal intuition. Perhaps it is because this intuition is inherently linear; indeed, deterministic chaos *cannot* occur for linear systems. More likely, it is because of our deeply ingrained view of a "clockwork universe," a view which in the West was forcefully stated by the great French mathematician and natural philosopher Laplace. If one could know the positions and velocities of all the particles in the universe and the nature of all the forces among them, then one could chart the course of the universe for all time to come. In short, from exact knowledge of the initial state (and the forces) comes an exact knowledge of the final state. Indeed, in Newtonian mechanics, this belief is true.

However, in the real world exact knowledge of the initial state is not achievable. No matter how accurately the velocity of a particular particle is measured, one can demand that it be measured more accurately. Although we may, in general, recognize our inability to have such exact knowledge, we typically assume that if the initial conditions of two separate experiments are *almost* the same, then the final conditions will be *almost* the same. For most smoothly behaved, "normal" systems, this assumption is correct. But for certain nonlinear systems, it is false, and "deterministic chaos" is the result.

At the turn of this century, Henri Poincaré, another great French mathematician and natural philosopher, understood this possibility very precisely and wrote (as translated in *Science and Method* [42]):

"A very small cause which escapes our notice determines a considerable effect that we cannot fail to see, and then we say that the effect is due to chance. If we knew exactly the laws of nature and the situation of the universe at the initial moment, we could predict exactly the situation of that same universe at a succeeding moment. But even if it were the case that the natural laws had no longer any secret for us, we could still only know the initial situation *approximately*. If that enabled us to predict the succeeding situation *with the same approximation*, that is all we require, and we should say that the phenomenon had been predicted, that it is governed by laws. But it is not always so; it may happen that small differences in the initial conditions produce very great ones in the final phenomena. A small error in the former will produce an enormous error in the later. Prediction becomes impossible, and we have the fortuitous phenomenon."

In the physical sciences, the concept of deterministic chaos has already clarified a number of previously inaccessible phenomena, including for instance aspects of the transition to turbulence in fluids. An example relevant to our later discussion concerns the essential limits to the predictability of weather. Although weather prediction on the scale of a few days is currently accurate to an extent unimaginable a few decades ago, the theory of deterministic chaos tells us that we cannot increase this prediction time much further, for the effort that would have to be expended on data collection and computer simulation grows *exponentially* with the desired forecasting time. This is a clear illustration of the type of quantitative limitations that deterministic chaos imposes on environmental modeling. But even in those cases in which chaos has not

given us greater quantitative insight into how to model a specific process, it has broadened our view of the possible outcomes of models and deepened our understanding of the complexities of the behavior of nonlinear systems.

To achieve our goal of exemplifying the consequences of nonlinear effects such as bifurcations and chaos, we shall take advantage of another recently understood property of nonlinear systems—"universality"—which implies that the essential features of a particular behavior in a general nonlinear system can be deduced from studying the simplest system which exhibits this behavior. Thus instead of dealing with the extremely complicated models necessary to describe real environmental issues, we shall instead introduce and study a sequence of simple models which illustrate the increasingly complicated behavior that can arise when the nonlinearity is properly taken into account. We apologize in advance to mathematically sophisticated readers and trust they will accept our deliberately over-simplified presentation in the sense in which it is intended.

In Section II we begin with perhaps the most basic of all environmental issues—namely, population dynamics—and present a very condensed historical perspective on the development of models for the growth of populations of single species. Starting from the familiar elementary model of (exponential) population growth originally due to Malthus, we show that the inclusion of nonlinear effects, such as limits to growth and the discreteness associated with species not having continuous reproduction, alters dramatically the expected dynamics of the populations. In particular, we show that in certain circumstances nonlinear models of population dynamics can predict periodic "cycles" in which the population oscillates in time. We also show that in other circumstances these same models can predict erratic, non-periodic population fluctuations: as we shall see, these fluctuations are described by deterministic chaos. We explore the origins of this behavior and attempt to develop an intuitive feel for its consequences.

In Section III, we turn to (still very simplified) models of two other issues of considerable relevance to technology-based confidence building: namely, weather prediction and strategic/economic competition. These models also exhibit the characteristic features of nonlinearity, including bifurcations from one type of behavior to another and, for certain ranges of their parameters, deterministic chaos. We discuss how this behavior limits our ability to anticipate and predict the outcomes of various situations.

Finally, in Section IV, we close with a few remarks on our general theme, stressing that despite its limitations and because of its challenges mathematical modeling of complex environmental and socio-political issues is crucial to any efforts to use technology to enhance international stability and cooperation.

II. THE EVOLUTION OF SIMPLE MODELS FOR POPULATION DYNAMICS

One of the first-studied and still most important environmental issues is that of population dynamics. Clearly the nature and rate of growth of the human population is of central interest to environmental planners, but so also are a number questions concerning the population dynamics of competing species, involving predator/prey, parasite/host, or exploiter/victim relationships. Further, at the elementary level, the mathematical models describing population dynamics are simple to describe and easy to motivate. Thus it is natural to use them as a means of introducing the nonlinear phenomena that we wish to discuss.

The simplest models of the population dynamics of a single species involve the evolution in time of a single variable which represents the total population of that species. Models describing the competitive or symbiotic relationships among several species will typically involve several variables, one for each of the

individual populations. Despite the very abbreviated and selective history presented here, one can see in the development of these models essentially all the general features to which we referred in the introduction.

A. Malthusian Dynamics and Exponential Growth

At the end of the 18th century, in his *Essay on the Principle of Population*, Malthus [32], based on the delicately phrased postulate that "the passion between the sexes is necessary, and will remain nearly in its present state" formulated the conclusion that "population, when unchecked, increases in a geometrical ratio." Although Malthus in fact recognized immediately that such unbounded growth would not be possible and discussed in his essay many checks on growth, nonetheless the model now inextricably linked to his name is that which describes the growth of an isolated system evolving continuously in time in a constant environment and facing no limits to growth. In the precise language of modern differential calculus, if one defines the population at time t to be $N(t)$ and notes that, by Malthus' postulate, the rate of change in time of the population—denoted by $\frac{dN}{dt}$—is proportional to $N(t)$ itself, one finds

$$\frac{dN(t)}{dt} = rN(t). \tag{1}$$

In this equation r is a *constant* which represents the "fecundity" (i.e., the efficacy of reproduction) of the population; clearly it is an essential parameter, in that it entirely determines the dynamics of the population. Indeed, the solutions to (1) can be given explicitly and their nature is determined by the value of r. If the population at a time $t = 0$ has an initial value $N(0) = N_0$, the size of the population at any later time t is given by

$$N(t) = N_0 e^{rt}. \tag{2}$$

The solutions represent either unbounded exponential growth (for $r > 0$, see Fig. 1) or exponential decay ($r < 0$, see Fig. 2). For the particular case of $r = 0$, the population remains constant.

Viewed as a dynamical system, the "Malthus equation" (1) is extremely simple. It is linear—the variable $N(t)$ occurs only to the first power in the equation, so that adding together two different solutions to (1) still gives a solution—and, as (2) shows, can be solved analytically exactly for all time and for all initial conditions. For general r, there is only one "fixed point"—i.e., a value of $N(t)$ such that $\frac{dN(t)}{dt} = 0$, so that population that does not change in time—and that is $N(t) = 0$: no population at all!

Although (1) is linear, the parameter value $r = 0$ is a point of "bifurcation" in the sense discussed in the introduction, for there is a fundamental change in the nature of the solutions at that point. However, as we shall see, the nature of the change in behavior is very much simpler than the complex bifurcation structure observed in typical nonlinear systems. Note also that, except at $r = 0$, the solutions are stable in the sense that their nature does not change for small changes in r.

The Malthus equation is an excellent example of our earlier observation that the conclusions derived from a model can control our perceptions not merely of what is *likely* but also of what is *possible*. Malthus' work had enormous influence; indeed, the term "Malthusian" still retains its implication of inexorable and destructive growth. The idea that population growth was inexorable and eventually had to lead to crisis had profound influence on both the evolutionary theories of Darwin and the economic theories of Ricardo.

In view both of its wide application and of our present broader perspective that makes the Malthusian predictions for growth seem rather naive, it is important to stress that the Malthus equation actually often

works well in regimes in which limitations to growth are not yet effective. A very relevant example is the initial phase of growth of epidemics, which typically does follow the exponential form. Indeed, the *absence* of the expected exponential growth during the initial phases of the AIDS epidemic proved to be a key observation in the development of a mathematical model consistent with the true behavioral patterns of the various risk groups [12]. However, if extended beyond its region of validity, the naive exponential growth can lead to ridiculous results: an example is the amusing prediction, made in the last century in connection with an estimate the traffic development in New York City, that based on the rate at which the number of horse carriages was increasing, within the then foreseeable future all streets in New York would be covered by several feet of horse manure!

B. Continuous Logistic Dynamics and Limits to Growth

Two generations after Malthus' *Essay*, the Belgian social statistician Pierre-Francois Verhulst formulated and named the now-celebrated "logistic" equation to model the effects of limits to Malthusian growth of the population. Although there are many sources of limits to population growth, a fundamental one is the "carrying capacity" of the environment: namely, that if the population increases beyond a certain size, the environment is unable to support it, and the resulting reproduction rate or "fecundity" becomes negative. One can model this effect by replacing the constant r in eqn. (1) by an expression of the form $r(N) = r(1 - N/N_\infty)$. Notice that this expression for $r(N)$ approximates the constant value r of the Malthus equations in the limit when populations are much smaller than N_∞; in this region exponential growth is quite reasonable. As the population grows, however, a point is reached beyond which the impact of the population on its environment can no longer be neglected and, in fact, there exists a maximal sustainable population size N_∞ which will be approached asymptotically.

The specific form of the (continuous time) logistic equation is

$$\frac{dN(t)}{dt} = rN(t)(1 - \frac{N(t)}{N_\infty}). \tag{3}$$

The logistic equation is clearly nonlinear—note the presence of a term proportional to $N(t)^2$—and possesses *two* fixed points: $N(t) = 0$ and $N(t) = N_\infty$. Considering only the physically relevant case of positive intrinsic fecundity $r > 0$, we find that the fixed point at $N = 0$ is *unstable*—that is, solutions perturbed slightly from it grow in time— whereas that at $N = N_\infty$ is *stable*. Despite the nonlinear nature of (3), since it involves only a single variable we can again find an analytical solution, which for the physically relevant case $r > 0$ is given by:

$$N(t) = \frac{N_0}{N_0 + (N_\infty - N_0)e^{-rt}}. \tag{4}$$

In Fig. 3 we plot several solutions of the logistic equation for different initial conditions. Note that for initial values larger than the equilibrium solution, the population *decreases* until it reaches the stable fixed point value of N_∞, whereas for smaller initial values the population *increases* to this value. Further, changes in the parameter r will induce no quantitative changes in the long-time dynamics of the system. Therefore robust predictions can be made: if there is any population at all, it has a unique long-term future, with the asymptotic population given by N_∞. As we shall see below, this strong predictability is not expected in more realistic models.

C. Discrete Logistic Dynamics and Deterministic Chaos

An important feature of the population dynamics of many species [34] is that reproduction is episodic rather than continuous in time: for certain insects, for example, the population in a given year can be expressed as a function of the population in the previous year. Mathematically, this means that the continuous-time, differential equation (3) above is replaced by a discrete-time "map", which relates the population at one discrete value of the time to that at the next discrete value. This seemingly minor change in the mathematical structure of the equations has a profound impact on the possible modes of behavior of the population.

To underscore this qualitative difference, let us change notation by labeling the discrete sequence of times by the integer n and using the variable x_n to denote the population at "time" n. If for simplicity we scale the carrying capacity of the environment to the value 1, then the discrete logistic "map" takes the form

$$x_{n+1} = r x_n (1 - x_n) \tag{5}$$

One can show that in order that the population never become negative, the values of x_n must be restricted to $0 < x_n < 1$ and the allowed values of the "fecundity" r must satisfy $0 < r \leq 4$. The development of the population is determined by iterating the map as many times as desired, and one is particularly interested in the behavior as "time"– that is, n, the number of iterations, approaches infinity. Specifically, if an initial population is picked at random in the interval (0,1) and iterated many times, what is the behavior of the population after all the "transients" have died out ?

It turns out that this behavior depends critically on the fecundity parameter and exhibits in certain regions "bifurcations"—the sudden and dramatic changes in response to small variations mentioned in the introduction—in r. For $0 < r < 1$, one can show that the value of x_n drops to 0 as n approaches infinity no matter what its initial value. In other words, after the "transients" disappear all points in the interval (0,1) are "attracted" to the *attracting fixed point* at $x = 0$. By standard mathematical techniques, the (linear) stability of this fixed point can be studied [19] and one can show that for $r < 1$ this fixed point is stable. Thus these low values of fecundity are insufficient to sustain any population at all, and the species dies out.

At precisely $r = 1$, there is a bifurcation, and the fixed point at $x_n = 0$ becomes unstable and is replaced by another fixed point, the value of which depends on r. This value is readily calculated, since at a fixed point $x_n = x_{n+1} = x^*$; substituting this into equation (5), we find

$$\lim_{n \to \infty} x_n = x^*(r) = 1 - \frac{1}{r}. \tag{6}$$

Hence as the value of r moves from one towards three, the value of the fixed point x^* moves from zero toward two-thirds. In population terms, the species approaches a fixed final population; this is just like the behavior observed above in the *continuous-time* logistic model for population dynamics, apart from the additional subtlety that for eqn. (5) the asymptotic value of the population depends on the fecundity. Again, a stability analysis shows that this fixed point is stable in the range $1 < r < 3$.

A more interesting bifurcation occurs as $r = 3$. Suddenly, instead of approaching a single fixed point, the long-time solution oscillates between *two* values: the model has an *attracting limit cycle* of period 2 and predicts that the asymptotic population will undergo "biennial" cyclic variations! As one further increases r, the behavior of the asymptotic population becomes incredibly complicated, as shown in Fig. 5, which

depicts the attracting set—that is, the asymptotic population—in the logistic map as a function of r. Here we see clearly the bifurcation at $r = 3$ to the period-two limit cycle. But more strikingly, as r moves toward 3.5 and beyond, there are also first period-4 and then period-8 limit cycles and then a region in which the attracting set becomes incredibly complicated. In fact, if one analyzes the logistic map carefully, one finds that, as r is increased, after the period-8 cycle come cycles with periods 16, 32, 64, and so forth, with the process stopping only as the period goes to infinity. All this occurs in the *finite* region of r below the value $r_c = 3.56...$. This (infinite) sequence of bifurcations is, quite naturally, termed a "period-doubling cascade," and is now recognized as one of the classic routes from regular to chaotic behavior. At many (but not all, as Fig. 5 shows) values of r above r_c the attracting set shows no apparent periodicity whatsoever and indeed consists of a sequence of points x_n that never repeats itself. For these values of r, the simple logistic map exhibits "deterministic chaos" and the resulting attracting set—far more complex than the attracting fixed points and limit cycles seen below r_c—is called a "strange attractor."

Although one can develop a more formal mathematical description, the essence of deterministic chaos can be appreciated by noting several distinct features of this behavior. First, for the values of r where the motion is chaotic, there is exactly the "sensitive dependence on initial conditions" on initial conditions that was anticipated by Poincaré; if two initial populations are chosen very close to each other, the distance between their successive iterations diverges exponentially and after a short time the resulting population histories become as different as two separate coin-toss sequences. Second, the sequence is not only non-periodic but also does not consist of any finite number of different periods superposed; in the appropriate mathematical jargon, the Fourier transform of the time series—which time series is shown in Fig. 4—does not have a series of distinct peaks corresponding to discrete frequencies but instead consists of a broad band of frequencies, a form traditionally associated with random external "noise."

In view of the complexity of the attracting sets above r_c, it is not at all surprising that this model, like the typical problem in chaotic dynamics, defied direct analytic approaches. There is however, one elegant analytic result—made all the more relevant in the context of this meeting by its having been discovered at Los Alamos by Stan Ulam and John von Neumann—that quantifies the sensitive dependence on, and loss of information about, initial conditions that characterize deterministic chaos. Consider the particular value $r = 4$. Letting $x_n = sin^2 \theta_n$, then for $r = 4$ the logistic map can be rewritten

$$\begin{aligned} sin^2 \theta_{n+1} &= 4 \, sin^2 \theta_n \, cos^2 \theta_n \\ &= (2 \, sin \, \theta_n \, cos \, \theta_n)^2 \\ &= (sin \, 2\theta_n)^2 . \end{aligned} \tag{7}$$

Hence the map is simply the square of the doubling formula for the sine function, and we see that the solution is $\theta_{n+1} = 2\theta_n$. In terms of the initial value, θ_0, this gives

$$\theta_n = 2^n \theta_0 \tag{8}$$

This solution makes clear, first, that there is a very sensitive dependence on initial conditions and, second, that there is an exponential separation from adjacent initial conditions. By writing θ_n as a binary number with a finite number of digits—as one would in any digital computer—we see that the map amounts

to a simple shift operation. When this process is carried out on a real computer, round-off errors replace the right-most bit with garbage after each operation and each time the map is iterated one bit of information is lost.* If the initial condition is known to 48 bits of precision, then after only 48 iterations of the map no information about the initial condition would remain. Said another way, despite the completely deterministic nature of the the logistic map, because of the exponential separation of nearby initial conditions, except for very short times, all information about the motion is encoded in the initial state, and none is in the dynamics themselves.

More mathematically, it can be shown that for $r = 4$ the logistic map leads to an asymptotic population which covers the whole interval of possible values of x densely, with a frequency distribution of points $\rho(x)$ in the allowed interval $0 < x < 1$ given by $\rho(x) = \frac{1}{\sqrt{x(1-x)}}$. Further, the transformation we performed for r =4 shows that the logistic equation is equivalent to a "Bernoulli process" generated by a bit-shift operation. This process is the basis of many modern (pseudo) random number generators used in computers. Finally, for $r = 4$ we can make precise the statement that the deterministic dynamics of the logistic map leads to behavior as "random as a coin toss." Let us divide the unit interval into two parts and assign the symbol H to all values $x_n < 0.5$ and T to all values $x_n > 0.5$. If we record only the sequence of H's and T's then for this value of r we cannot distinguish the logistic dynamics from a true coin-toss.

There is still much more that we can learn from this simple example, but lack of space compels us to be brutally brief in the descriptions of the following results. First, one can ask how typical for more general nonlinear systems is the "period-doubling cascade" that marked the transition from regular to chaotic behavior in the logistic map. It turns out that this "period doubling cascade" is by no means the only manner in which dissipative nonlinear systems move from regular motion to chaos. Many other routes—among them "quasi-periodic," "intermittent," and so forth—have been identified and analyzed.

Second, if, however, the period-doubling cascade is observed in a system, it is possible to argue theoretically that there are "universal" features of this cascade that do not depend on the specific nature of the logistic map; this very important theoretical result concerning "universality" in nonlinear dynamics was confirmed by the observation of these universal features of period doubling in an actual fluid experiment. We shall later refer to an illustration of this universality in a model of weather prediction.

Third, Fig. 5 illustrates one additional obvious feature of the attracting set of eqn (5): namely, that it contains non-trivial—and, in fact, self-similar—structure under magnification. Indeed, in the mathematical model this self-similar structure occurs on all (smaller) scales; consequently, this figure is one example of a class of complex, infinitely ramified geometrical objects called "fractals" that typically arise in chaotic dynamical systems. Importantly, this fractal structure occurs in the space of parameters—here r—of the problem. There are also important examples where fractals are observed in the space of initial values of the problem.

Fourth, whereas in both the continuous-time logistic dynamics and the logistic map there exists for any given value of r only one attractor, in more general nonlinear dynamical systems one can find multiple attractors and asymptotic modes of behavior. In these cases, the initial conditions from which the evolution starts will determine to which final attractor the system will evolve asymptotically. The set of all initial configurations which lead to the same attractor is called "basin of attraction" for that attractor. One can show that the boundaries between these basins of attraction can also have the very complicated "fractal" structure discussed above [22]. In that event, the system will exhibits another form of "sensitivity to initial

* In many computers the shift operation replaces the right-most bit by a zero, which then leads to a spurious globally attracting fixed point at $\theta = 0$.

conditions" in the sense that the attractor to which the system evolves, depends very sensitively on the precise initial condition. Note that this is true even if the attractor itself is not chaotic; a well-known example is a roulette wheel, where the final state is always a fixed point—one of the numbers on the wheel—but which fixed point depends, to the grief of many, very sensitively on the initial conditions. Note also that if the system does have multiple attractors, transitions between these attractors can be induced by external fluctuations. In many cases it turns out that there exists a very large variation in the robustness of these attractors against external noise: that is, some are considerably more stable than others. This range of stability can mean that in realistic environments only a few of the possible attractors are actually observed. In particular, as a result of this noise sensitivity, one can observe [36] the disappearance of chaos via a "noise-induced order."

Fifth, within the region $r_c < r < 4$, the logistic map exhibits a number of more subtle phenomena associated with chaos. At $r = r_c$, the actual type of deterministic chaos exhibited by the map is known as "noisy periodicity." In noisy periodic chaos there exists a periodic oscillatory pattern with a small-scale chaotic modulation of the amplitude. In Fig. 5 these solutions appear as chaotic bands. The chaotic bands are interspersed with periodic windows, which typically are quite sensitive to external fluctuations. The phenomenon is that the increase of a given parameter (the fecundity, in our example) leads to chaotic solutions but then a further increase of the same parameter suddenly restores orderly motion. The behavior associated with this return of regularity is named "intermittency" after a related phenomenon observed in fluid turbulence. Intermittent chaos exhibits an irregular alternation of ordered behavior and chaotic bursts. The duration of such regular motion can become extremely long such that the system appears to be non-chaotic until a surprising burst of chaos reveals the underlying complexity. In the context of environmental processes intermittency-type phenomena, basically irreproducible failures of the standard behavior of the system, seem not to be too rare. The inverse phenomenon is also observed: namely that a seemingly robust chaotic behavior suddenly decays to a regular periodic attractor or a fixed point in what is technically known as a "crisis" event [22].

Finally, in view of the prominence of continuous-time models, it is important to indicate the level of complexity that they must contain in order to exhibit chaos. For systems involving only two coupled first-order differential equations—for example, simple population equations describing competing species such as predator/prey or host/parasite—the most complex behavior that can occur is a limit cycle, analogous to those seen in the logistic map for $3 < r < r_c$. However, when one considers three coupled first-order differential equations, then one can observe deterministic chaos. In the next section, we shall give an example of this in the context of modeling weather forecasting.

III. CHAOTIC DYNAMICS IN MODELS FOR WEATHER PREDICTION AND STRATEGIC COMPETITION

We turn now to a discussion of models for two phenomena—weather prediction and strategic competition—which are quite significant for considerations of technology-based confidence building. Although the models discussed in the ensuing subsections *cannot* be taken as realistic models of the phenomena they caricature, they *can* be viewed as "half-way houses" between the very simple models discussed above and actual models of complex environmental phenomena. Their value is thus in indicating that the effects of nonlinearity—including bifurcations and deterministic chaos—are indeed likely to occur in more realistic models.

A. Weather Prediction and the Lorenz Equations

In the early 1960s Edward Lorenz, a meteorologist at MIT, began a series of investigations aimed at establishing that unpredictability in weather forecasting was not due to any external noise of randomness but was in fact compatible with a completely deterministic description. In a sense, Lorenz [30] was quantifying another qualitative insight of Poincaré, who in another prescient comment—all the more remarkable for its occurring in the paragraph immediately following our earlier quote from *Science and Method*—captured both the importance and the difficult of meteorology:

"Why have meteorologists such difficulty in predicting the weather with any certainty? Why is it that showers and even storms seem to come by chance, so that many people think it quite natural to pray for rain or fine weather, though they would consider it ridiculous to ask for an eclipse by prayer? We see that great disturbances are generally produced in regions where the atmosphere is in unstable equilibrium. The meteorologists see very well that the equilibrium is unstable, that a cyclone will be formed somewhere, but exactly where they are not in a position to say; a tenth of a degree more or less at any given point, and the cyclone will burst here and not there, and extend its ravages over districts it would otherwise have spared. If they had been aware of this tenth of a degree, they could have known it beforehand, but the observations were neither sufficiently comprehensive nor sufficiently precise, and this is the reason why it all seems due to the intervention of chance. Here, again, we find the same contrast between a very trifling cause, inappreciable to the observer, and considerable effects, that are sometimes terrible disasters."

To demonstrate this sensitive dependence quantitatively, Lorenz began with a simplified model approximating fluid convection in the atmosphere. By expanding this model in (spatial) Fourier modes and by *truncating* the expansion to the lowest three modes, explicitly ignoring higher couplings, Lorenz obtained a closed system of three nonlinear first-order differential equations:

$$\begin{aligned} \frac{dx}{dt} &= -\sigma x + \sigma y \\ \frac{dy}{dt} &= -y + rx - xz \\ \frac{dz}{dt} &= -bz + xy \end{aligned} \tag{9}$$

In the application to atmospheric convection, x measures the rate of convective overturning, and y and z measure the horizontal and vertical temperature variations, respectively. There are three control parameters in (9)—σ, r, and b—which can be related to physical characteristics of the flow. Obviously, the nature of the solutions to eqn (9) is likely to depend strongly on the values of these parameters. We shall focus on a few illustrative cases. For simplicity, we fix values of the parameters $\sigma = 10$ and $b = 8/3$, and discuss several values of r [50].

For values of $r < 1$, all initial conditions for the Lorenz equations eventually evolve to a fixed point at the origin, $(x = y = z = 0)$. This is directly analogous to the behavior of the discrete logistic map for small values of its parameter. For $r > 1$, the fixed point at the origin becomes unstable, but for r less than about 24 all initial conditions are attracted to one of two coexisting fixed points: either $C_1 = (x = (\frac{8}{3}(r-1))^{\frac{1}{2}}, y = (\frac{8}{3}(r-1))^{\frac{1}{2}}, z = r-1)$ or $C_2 = (x = -(\frac{8}{3}(r-1))^{\frac{1}{2}}, y = -(\frac{8}{3}(r-1))^{\frac{1}{2}}, z = r-1)$.The two basins of attraction of these fixed points change in complicated ways as r is increased , but no other attractors appear for $r < 24$. For larger values of r, the nature of the attracting set itself changes dramatically, and one finds

the celebrated "Lorenz (strange) attractor," three perspectives of which are shown in Fig. 6. This attractor represents a solution to eqn (9) which is contained completely in a bounded region of the $\vec{x} = (x, y, z)$ space but which never comes back on itself. Since solutions of differential equations correspond to continuous curves, the solutions to the Lorenz equations $\vec{x}(t) = (x(t), y(t), z(t))$ to be defined at all times $-\infty < t < \infty$ must be of infinite length, if they are not asymptotic to a closed curve. If the full attractor, generated by the infinite time series of points $(x(t), y(t), z(t))$ were plotted, one would see the trajectory looping around forever, never intersecting itself and hence never repeating. The exquisite filamentary structure seen in Fig. 6 would exist on all scales, and even in the limit of infinite time the attractor would not form a solid volume in the (x, y, z) space. Again, this is a characteristic of "fractals", for which the concept of dimension is generalized to non-integer values, expressing the fact that these objects in some sense lie "between" regular Euclidean objects such as ordinary lines, surfaces, and solids. (see e.g. [[33], [38]]). In the case of the Lorenz attractor, the fractal dimension is approximately $D = 2.07$.

If one continues to change the value of r, numerous additional bifurcations occur. Some involve the re-appearance of regular motion and, in particular, one can find examples of the "period-doubling cascade" to chaos (in particular, in the region just above $r = 215$). Importantly, as we anticipated in our discussion of "universality", many characteristics of this cascade in the Lorenz equations are identical to those seen in the logistic map. Another less rigorous and more qualitative aspect of this universality is that similar equations have been shown also to describe approximately chaotic behavior of certain types of lasers (see e.g. [24]).

From the perspective of the original weather-prediction problem, the existence of the strange attractor solution to the Lorenz equations implies that for a wide range of parameters the long-time behavior of the model simply cannot be predicted, for the sensitive dependence on initial conditions means that two points starting very near each other on the attractor evolve in time in dramatically different ways. In popular language, this is referred to as the "Butterfly Effect" [21]: whether a butterfly in Beijing flaps its wings three times or only twice can (in principle) alter totally the weather in San Francisco some days hence. The existence of deterministic chaos and strange attractors thus clearly indicates one type of limitation to mathematical modeling of nonlinear systems ranging from dripping faucets [48] through electronic devices and chemical reactions [24] to climatic oscillatory phenomena like "El Niño" [53] and perhaps even stock market dynamics (see e.g. [46]).

B. Model for Economic/Strategic Competition in Discrete Time

The pioneering work of Richardson [44] set the stage for subsequent attempts to analyze quantitatively many questions of strategic military and economic competition between—and among—nations. In this section we discuss a simple discrete variant of Richardson's equations [40], primarily as a brief exercise to indicate how one goes about formulating and analyzing nonlinear models of environmental issues. We recall that the original Richardson equations [44] as applied to the arms race between two nations have two variables evolving in continuous time. Thus they cannot exhibit more complex behavior than fixed points or limit cycles. However, as in the case of the continuous and discrete time versions of the logistic map, if one considers discrete time—representing, for example, the fact that budget decisions are typically approved on an annual basis—and adds nonlinear terms to represent limited economic resources, in the case of two nations one can observe all the striking features found in the nonlinear dynamical systems discussed above.

Since we have already discussed these effects in some detail, let us focus here on an extension to model an arms race among three nations; this introduces the additional complication of possible alliance formations (see for example [58]). With three nations the natural choice for an alliance is between the two weaker nations, as otherwise the two nations in the alliance would have dominant superiority over the third one and the competition could be reduced to that between the nations within the alliance. For the model, let us therefore assume that we have a situation in which the nations X, Y, Z have normalized arms expenditures amounting to values x_n, y_n, z_n, where the index n indicates a discrete time unit and corresponds to a typical decision period : for example, x_n can indicate the military budget in year n. We study the generic situation in which $x_n > y_n > z_n$. In this case, by our assumptions Y and Z would form an alliance against X. The equations describing the armament level in the year $n+1$ contain, for each nation, four relevant factors: (1) the armament level in the previous year (x_n, y_n, z_n); (2) the intrinsic self-armament level that each nation wants to acquire, independent of external threats (x_s, y_s, z_s); (3) the external threat from hostile nations; and (4) the economical limitations (x_m, y_m, z_m). The terms in the equations describing the external threats are different for nations who have to defend themselves against an alliance and those who are in an alliance. In the first case the threat consists of the sum of the expenditures of the adversaries, $(y_n + z_n)$, whereas in the second case the threat from the adversary X is reduced by the expenditures of the ally $(x_n - z_n)$ for Y, $(x_n - y_n)$ for Z.

We regard the arms expenditures—the x_n, y_n, z_n—as the variables whose time evolution we want to follow and the other variables—x_s, y_s, z_s and x_m, y_m, z_m—as parameters, analogous to the carrying capacity N_∞ in the simple logistic population dynamics. Pursuing this analogy further, we see that to couple the variables together we need the analog of the fecundity parameter, r. Here there are several parameters, which effectively represent the results of political decisions about rates at which goals are to be approached. The parameters (k_{11}, k_{22}, k_{33}) determine how fast each nation tries to achieve its intrinsic armament level independent of external threats, while the parameters (k_{23}, k_{13}, k_{12}) describe the rate at which a perceived external threat is countered. For the condition that $x_n > y_n > z_n$, the resulting discrete arms expenditures are given by:

$$\begin{aligned} x_{n+1} &= x_n + \Big[k_{11}(x_s - x_n) + k_{23}(y_n + z_n)\Big](x_m - x_n) \\ y_{n+1} &= y_n + \Big[k_{22}(y_s - y_n) + k_{13}(x_n - z_n)\Big](y_m - y_n) \\ z_{n+1} &= z_n + \Big[k_{33}(z_s - z_n) + k_{12}(x_n - y_n)\Big](z_m - z_n) \end{aligned} \tag{10}$$

If in the course of the simulation, the ordering in the arms expenditures is changed, the equations are rearranged in such a way that a new alliance is formed among the new minor powers. In view both of the large number of parameters and of the uncertainty in their individual values, one should study [40] the equations for a wide range of parameters and attempt to isolate those domains of parameters for which the solutions show robust, regular behavior from those in which sensitive, chaotic behavior is obtained.

A preliminary analysis [40] of typical solutions of this model shows (unsurprisingly) multiple attractors, separated by surfaces forming boundaries of the basins of attraction. There are indications for small-scale chaos in several regions of state space for certain combinations of parameters. It appears also that close to boundaries in parameter space at which transitions in the alliance structures take place, the system becomes (again, unsurprisingly) very sensitive to external noise. This phenomenon could be helpful in

the computational identification of crisis domains. Although no one could take the conclusions drawn from such an over-simplified model as the sole basis for any political decision, we feel that the attempt to understand and to quantify various causal relationships will lead to increasingly sophisticated models for specific aspects of these problems; when such models are produced, one will certainly need the insight gained from simpler models and the techniques of modern nonlinear dynamical systems theory to analyze these models.

IV. DISCUSSION AND CONCLUSIONS: THE LESSONS OF NONLINEARITY

Despite the rather sweeping title of our article, we have in fact discussed only a limited number of the challenges that the inherent nonlinearity of environmental and socio-political issues pose for mathematical modeling. For instance, by focusing on mathematical models expressed in terms of ordinary differential and difference equations, we have tacitly omitted the significant class of systems in which spatial variability is important. An environmentally significant example of this class of problems is fluid flow through porous media, which is essential to modeling both advanced oil recovery and ground-water pollution issues. These systems have typically been modeled by partial differential equations, which allow for continuous variation in time and in the spatial degrees of freedom. Recently, however, more discrete methods—loosely speaking, conceptually analogous to the use of the discrete logistic map in contrast to the continuous-time logistic dynamics—have proven to be of considerable value in analyzing such problems [25].

Nonetheless, even within our limited selection of topics we have described and illustrated many important concepts, including some that have only recently begun to creep into public awareness. First, we have learned to expect that nonlinear systems will exhibit *bifurcations*, so that small changes in parameters can lead to qualitative transitions to new types of solutions. The global greenhouse effect, discussed in this conference, may be an example of such a phenomenon: a small increase in the carbon dioxide concentration in the atmosphere may lead to a qualitative change in the global ecology. Similarly, possible bifurcation phenomena must be kept in mind in analyzing models both of environmental phenomena like ozone depletion and deforestation and of socio-political phenomena like population growth, trade imbalances, and the effects of technological innovations. Second, we have seen that apparently random behavior in some nonlinear systems can in fact be described by *deterministic chaos*, with its exquisite sensitivity to initial conditions and complex, aperiodic motion. The fundamental limitations on our ability to predict the weather are one consequence of deterministic chaos. Third, we have argued that in typical nonlinear systems there will exist *multiple basins of attraction* and that the boundaries between these different basins can have incredibly complicated *fractal* forms. This represents another form of sensitivity to initial conditions and consequent limit to prediction: even if all possible long-term behaviors of a system are simple, determining which one will occur for a given (imprecisely known) initial state can be essential impossible.

On the surface, these three insights seem rather depressing, since they appear to provide clear examples of limitations to our potential quantitative understanding even in the cases for which we have reliable models. But at a deeper level, there are many reasons to be encouraged about the future of mathematical modeling of complex nonlinear problems. Heightened general awareness of of the subtle interconnectivity and the limits to what we can know about the global consequences of local actions may lead to more care and restraint in confronting environmental issues. This prospect is essentially a positive restatement of our earlier remark that models guide our perceptions of what can happen as well as what is likely to happen. Further, on a more technical level there are several promising developments. The *universality* of certain nonlinear phenomena implies that we may hope to understand many seeming disparate systems in terms

of few simple paradigms and models. Thus, there is the possibility of what might be termed "intellectual technology transfer," in which features observed and understood in one phenomenon can be used to interpret another. In addition, the fact that deterministic chaos does follow from a well-defined dynamics with no random influences means that in principle one *can* predict behavior for short periods of time. In the case of the weather, for example, predicting the weather ten minutes ahead—old jokes about the weather in the mountains of New Mexico aside—is something that any of us can do by looking out the window. Although this seems obvious, recall that if the weather were really random on a moment-to-moment basis, even this limited prediction would be impossible. Recently, there has been considerable progress in developing more formal approaches to both forecasting and noise reduction using the theory of deterministic chaos (see for example [18] and references therein). These approaches have led to predictions for the behavior of certain chaotic systems which predictions are orders of magnitude more accurate than those based on classical forecasting methods. A more colorful (and earlier) example is described in "The Eudaemonic Pie" [4], in which, by making a series of measurements with the aid of a computer hidden in a shoe, students of chaos theory were able to "predict" the outcome of a roulette wheel with sufficient accuracy to beat the system (at least as long as the computer worked!!).

Another recent and equally exciting development in the application of chaos theory goes one step further: since chaotic systems are so sensitive to small perturbations, it also should be possible to use this enormous amplification of small perturbations to influence the system in a desired way. Instead of controlling a chaotic system through fast feedback mechanisms—which under certain conditions can actually exacerbate the situation by themselves, becoming the origin of new chaotic behavior—one can use the intrinsic "attracting" nature of nonlinear systems with dissipation to "entrain" the behavior to a desired dynamics ([28], [17], [41]) . This is a generalization to chaotic motions of an old technique widely used in the context of periodic signals to tune FM receivers. For a series of model examples and even for some actual experiments it has been shown that an optimal chaotic control exists [28]. It minimizes the energy necessary for the control and again can be many orders of magnitude more efficient than more traditional approaches. This new technique is especially useful for cases in which feedback is not possible, for example, when the dynamics consists of many independent or weakly coupled units which do not behave coherently. It is not hard to speculate on the utility of such a chaotic control methodology in environmental problems. For instance, in the atmosphere we have a complex situation with an inhomogeneous distribution of temperature, pressure, and moisture. Under certain conditions self-organization of these variables occurs and hurricanes or tornados are formed. Understanding the dynamics of those modes of behavior might make it possible to control the creation and destruction of such coherent structures through using the chaotic control methods of nonlinear dynamics.

On a still more speculative level, in studying the global climatic problems such as the greenhouse effect and ozone depletion we may learn that it is already too late to reverse the negative effects of man-made perturbations, such as carbon dioxide emissions, simply by reducing these perturbations. Perhaps we will be compelled to take active steps—for instance, creating hurricanes on the ocean to enhance carbon dioxide exchange, preventing the hurricanes from touching land, steering rain clouds to areas where desertification is threatened—to reverse these trends; a workable chaotic control theory would clearly be valuable in this context. Similarly, if we can build models which predict when and where earthquakes are likely to happen, we might trigger the earthquake through well-calculated small shocks and thereby make sure that it doesn't come as a surprise and that we have enough time to evacuate threatened areas. Again, chaotic prediction algorithms may prove relevant.

After such flights of fancy, it is perhaps most appropriate to end with the essential caveat that applies to all attempts to quantify complex issues such as those facing us in the environmental and socio-political

arenas. While mathematical models can force us to quantify our understanding of the causal relations among the various components of a complex issue and while the ability to analyze these models with the tools of modern nonlinear dynamics can sharpen our perceptions of what may occur, the fundamental limitations caused by the very complex nature of, and the inherent uncertainties in, these problems mean that these models must always be interpreted, to paraphrase Dickens, as images of what might be, rather than what must be. They can never substitute for human analysis, collective wisdom, and political will. Nonetheless, coupled with these attributes, mathematical modeling of environmental and socio-political issues can contribute vitally to the development of the technical-based confidence building which this conference has addressed.

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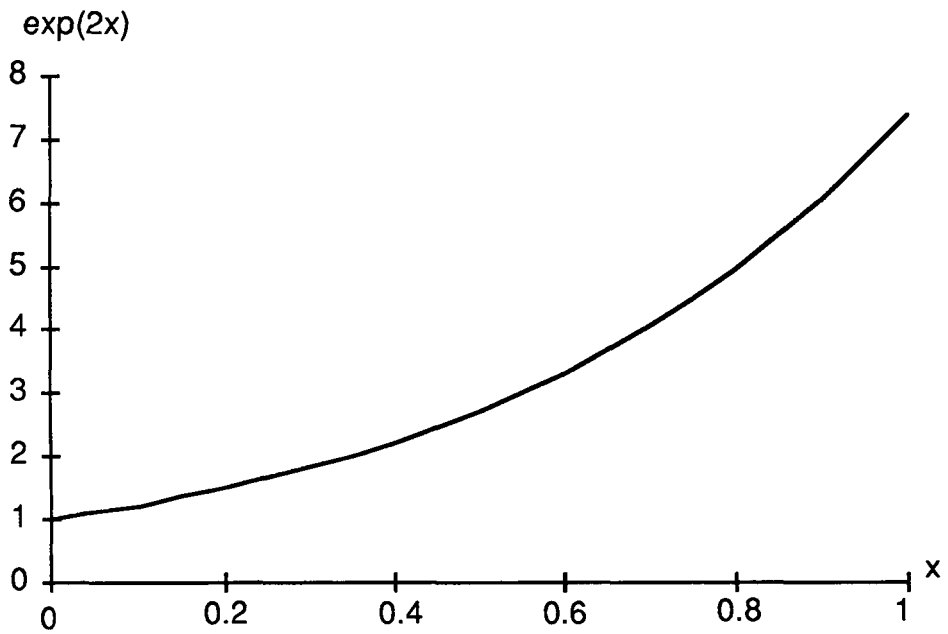


Figure 1. Exponential growth solution for Malthus' equation with positive growth factor. Without non-linear saturation the solution diverges to infinity.

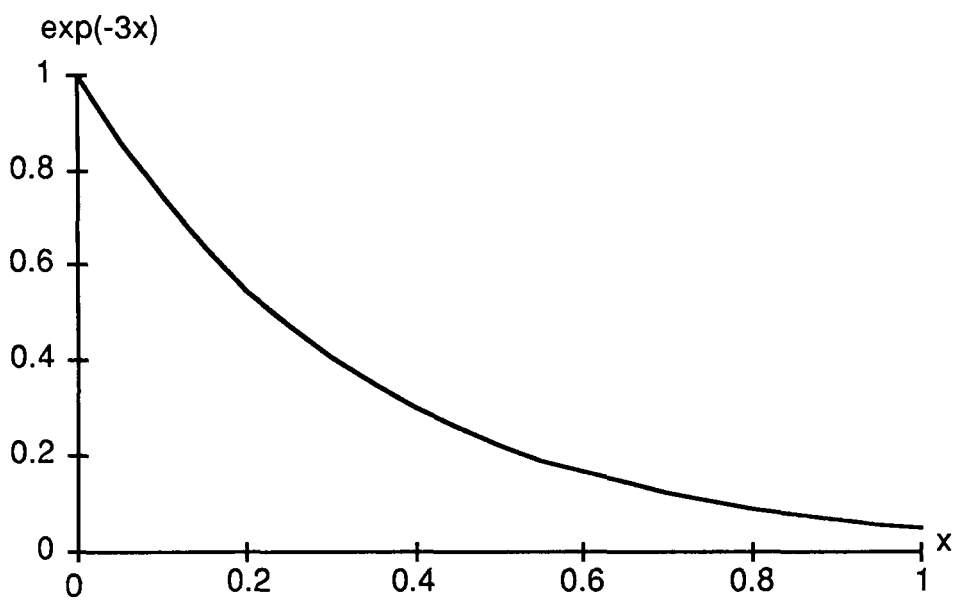


Figure 2. Exponential decay solution for Malthus' equation with negative growth factor. Asymptotically this solution tends to zero as time goes to infinity.

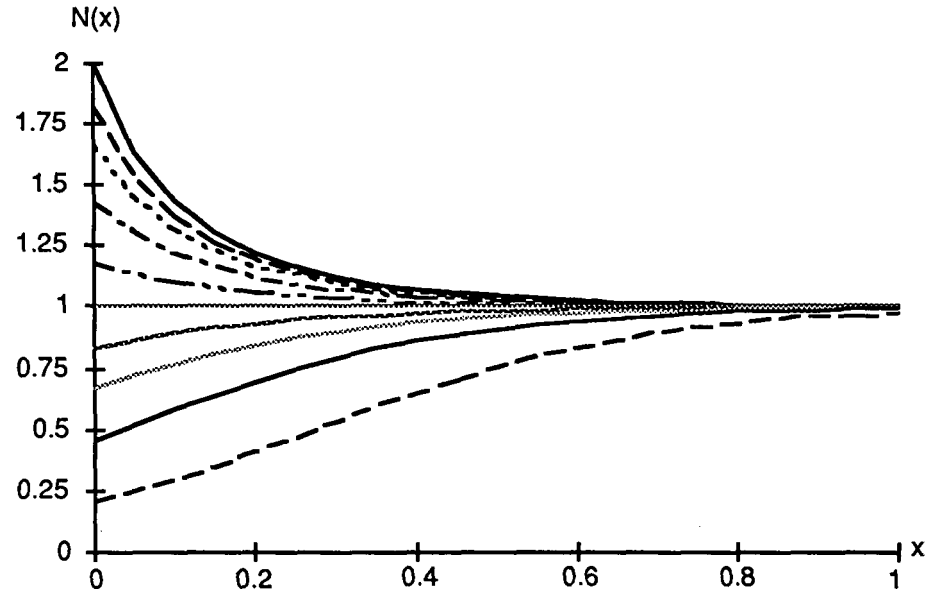


Figure 3. Several solutions of the Verhulst (logistic) equation for different initial conditions. All solutions with positive initial conditions approach asymptotically the stable fixed point solution $N = N_\infty$.

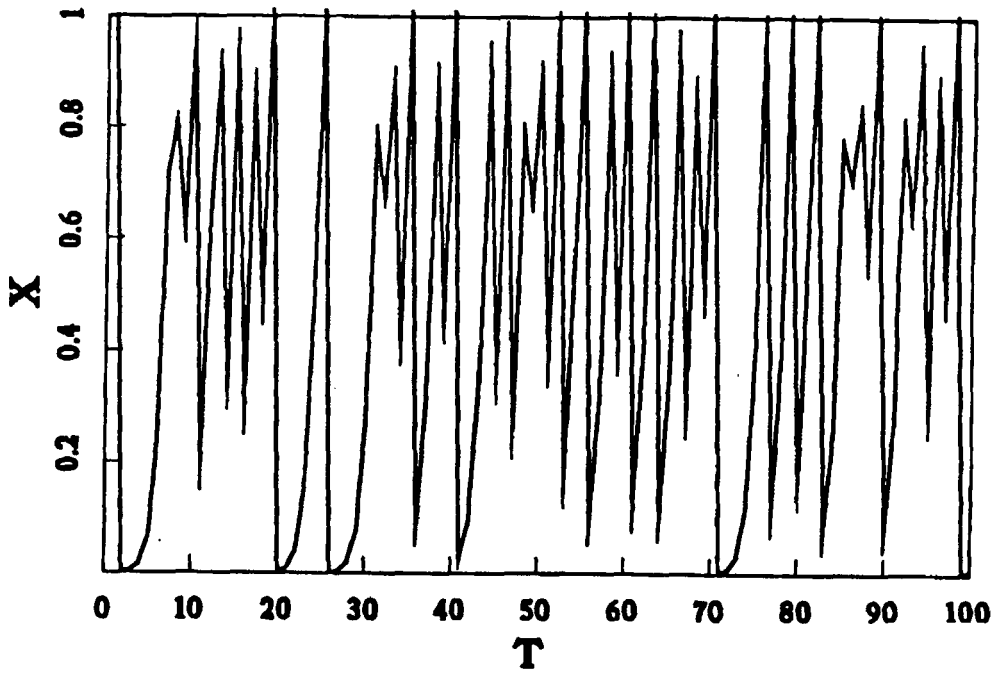


Figure 4. Chaotic solution of the discrete logistic equation for parameter $r = 4$ and initial condition $x_0 = 0.499$. The solution comes arbitrarily close to every point in the interval but spends most of the time close to the endpoints of the interval, because of the singularities in the invariant measure.

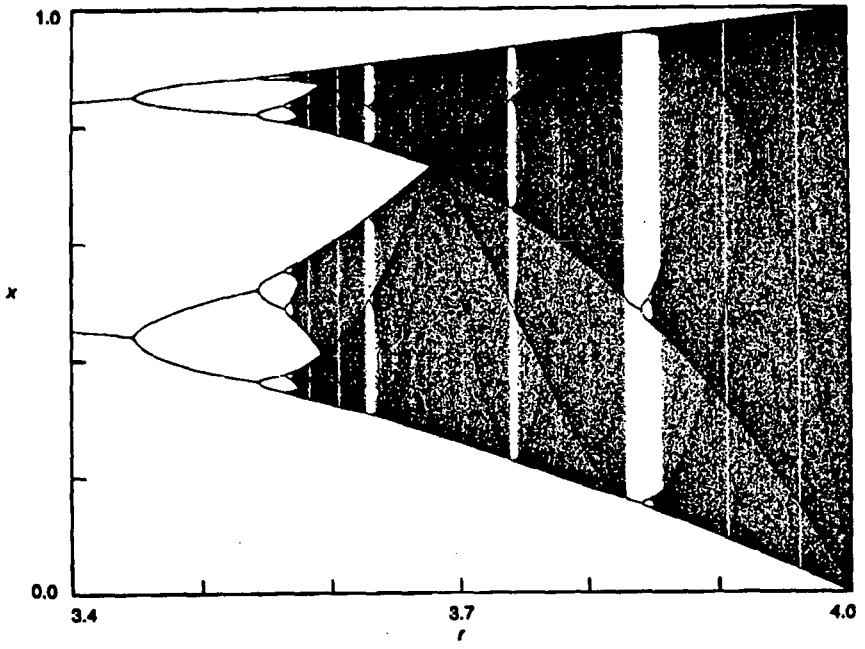


Figure 5. Bifurcation diagram of the discrete logistic equation for parameter $3.4 < r < 4$. The attractors of the system are plotted as point sets in the vertical direction versus bifurcation parameter r. Bright areas indicate periodic attractors.

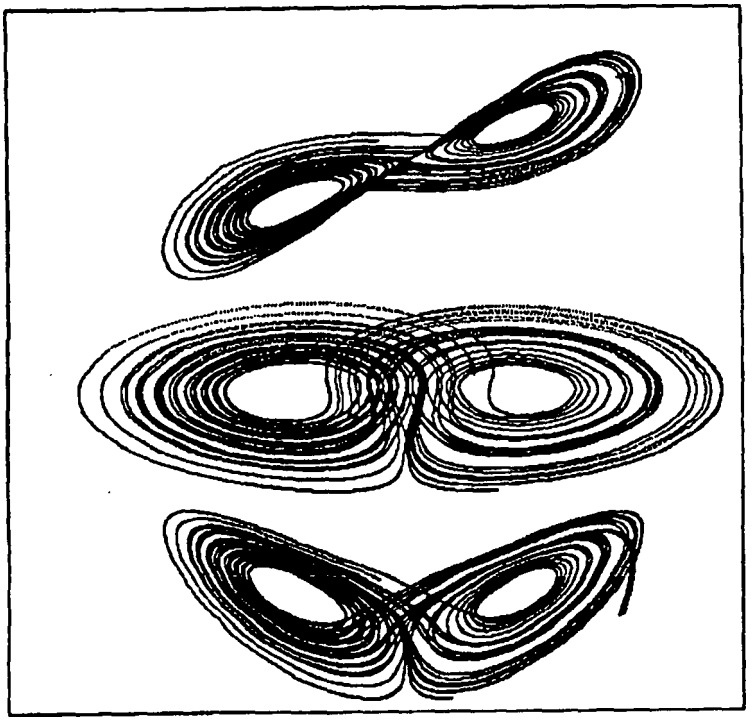


Figure 6. Projection of the Lorenz attractor onto the x-z plane. The attractor is chaotic and forms a fractal object of dimension slightly larger than two ($d_F \approx 2.07$). This indicates that solutions are wandering erratically on a geometrical object which locally consists of infinitely many closely spaced surfaces.

NUCLEAR WASTE: AN AGENDA FOR U.S.-SOVIET COOPERATION ON A VEXING GLOBAL PROBLEM

by

Luther J. Carter

On the defensive in much of the world, nuclear power remains beset by still unresolved problems related to nuclear waste, reactor safety, the safeguarding of explosive nuclear materials, and, certainly in U.S. experience, construction and operating costs that are unacceptably high. While all these problems deserve attention, I shall be speaking in particular of opportunities for the United States and the Soviet Union to mount major international initiatives to help the world cope with its growing accumulations of spent reactor fuel and high-level waste.

As I see it, the two superpowers now have a prime opportunity to meet this responsibility in a way that could help facilitate a major expansion of nuclear power—should this ever make economic and environmental sense—and also help put a more benign face on the civil atom.

Important new initiatives in spent fuel and waste management could be centered partly in or near sites long used for testing nuclear weapons, namely the Nevada Test Site near Las Vegas and the Soviet Union's Polygon test site near Semipalatinsk in eastern Kazakhstan. This could be of symbolic as well as practical importance, representing a step toward converting these sites from weapons testing to support of atomic energy.

The new spent-fuel and waste-management centers would include spent-fuel storage that is subject to International Atomic Energy Agency inspection and safeguards. These centers could be made to include special high-security facilities for plutonium and high-enriched uranium (HEU) from warheads of missiles dismantled under arms-reduction treaties. The HEU and plutonium would be kept in storage pending final disposal by fashioning these materials into reactor fuel or, in the case of the plutonium, perhaps by permanent isolation either in a deep geologic formation or in the deep seabed.

At the moment there are, I submit, two crying needs in spent-fuel and nuclear-waste management. One is for an international center for storage of spent reactor fuel. The other is for a new center dedicated to research and development aimed at reducing geologic isolation of spent fuel or high-level waste to a routine that offers predictable and acceptable results.

What I'm suggesting here is that an international center for spent-fuel storage be established in Kazakhstan and that a center for waste-isolation R&D be established in Nevada. Politically, the United States is not ready for international storage of spent fuel, in Nevada or anywhere else. But the Nevada center should provide temporary surface storage of spent fuel from American reactors as well as underground emplacement of at least modest amounts of such fuel for experimental purposes. Although sure to be hotly controversial (with much opposition from Nevadans), this might in the end be politically feasible.

At the Nevada center, as well as at the one in Kazakhstan, a special high-security facility should be established to receive fissile materials from dismantled weapons.

I'll discuss each of these propositions in turn.

THE SOVIET INITIATIVE

An international center for spent fuel storage is needed by nations that face growing inventories of spent fuel yet do not wish—or should not wish—to have the fuel reprocess- ed either at established fuel cycle facilities in France and Britain or at new ones that might be established in other countries. I should note parenthetically that Germany recently abandoned construction of its controversial Wackersdorf reprocessing plant in Bavaria and now plans to rely on the French and British reprocessors; Japan is also heavily committed to major contracts with the French and British reprocessors but still intends to build a reprocessing plant at Rokkashomura in northern Honshu. Given the present glut of uranium, fuel reprocessing for the recycling of plutonium is without economic justification.

There are moreover the risks of nuclear proliferation and nuclear terrorism.[1] Even if initially confined to nations such as Britain and France that already possess nuclear weapons, plutonium recycling can serve as an example and excuse for other nations to acquire plutonium stocks, which sooner or later may lead them to build such weapons. And shipment of plutonium within Europe and around the world for use as fuel could tempt terrorists to steal or forcibly seize some of this dangerous material and mount bomb threats.

Why do I speculate that the Soviet Union may wish to provide a spent-fuel storage center? One reason is that for years the Soviet Union has been taking back spent fuel from Soviet-built reactors in Eastern Europe. The first sign that the Soviet Union would, for a fee, welcome spent fuel of non-Soviet origin came in early 1985 when a formal offer was made to Austria to accept fuel from the controversial Zwentendorf reactor.[2]

There was speculation at the time that what motivated the Soviet offer was a desire not to let the Chinese—who had been making similar overtures to European utilities—get ahead of them. Nothing came of the Soviet offer, for the Austrians soon abandoned all idea of a startup at Zwentendorf.

Since that time, however, there have been other indications of interest by the Soviets in the idea of accepting spent fuel of non-Soviet origin for storage as a commercial service. Always short of hard currency, the Soviets are by no means indifferent to the billions of dollars that might well be earned.

The Soviets might also favor undertaking such an initiative because it would strengthen the international nonproliferation and safeguards regime, which they have traditionally supported. Indeed, it would be something of a reprise, on a strictly voluntary basis, of the Carter administration initiative calling for an International Spent-Fuel Storage project.

That initiative contemplated having countries that sell reactor fuel insist that their foreign customers agree to commit their spent fuel to the international storage facility once it was established. The initiative failed because nations such as France, the United Kingdom, and Germany saw it as inimical to their ongoing or planned commercial reprocessing ventures.

A particularly attractive aspect, I should judge, of setting up a spent fuel storage center on or near the Semipalatinsk test site would be to further Mikhail Gorbachev's declared goal of converting defense facilities to civilian purposes. Gorbachev has, moreover, called for an end to all nuclear weapons testing.

The Semipalatinsk site, though remote, is accessible by rail to other parts of the country and to ports on the Black Sea. Known as the "Polygon," it covers thousands of square kilometers. Moreover, deep geologic sites suitable for final isolation of nuclear waste may well be present either on the test site or somewhere else within the larger region of eastern Kazakhstan.

The region is semi-arid, of modest relief (elevations are typically on the order of 200 meters), and is more stable tectonically than Nevada, though earthquakes are known to occur. More generally, it is an old shield area of granitic and other crystalline rocks left from the erosion of ancient mountains, with a number of large granitic plutons or batholiths present.[4] The United States and other western countries such as France, Canada, and Sweden are by now quite practiced at investigating crystalline rock bodies for purposes of waste isolation. They could help the Soviets identify promising sites.

Used for nuclear weapons testing since the 1950s, the region has recently seen a remarkable amount of "confidence-building" cooperative activity. Indeed, as you know, only a few years ago American seismologists established three monitoring stations around the Polygon as part of the nuclear-test-ban verification project that the Natural Resources Defense Council initiated with the Soviet Academy of Sciences.[5] Then, last September, scientists for the US Department of Energy were at the Polygon itself monitoring a weapons test. This followed by about a month the monitoring by Soviet scientists of a similar test in Nevada.

THE US INITIATIVE

For its part, the United States should, I submit, mount an international initiative aimed at making possible, in a variety of geologic environments, complete containment of nuclear waste over the period of hazard. This would represent a philosophy of essentially "zero release" analogous to the philosophy of "inherent safety" that some reformers now favor for power reactors. The present policy and regulatory strategy is to delay releases long enough and keep them low enough that contamination of groundwater or surface waters will not be such as to harm more than a few people in any one generation—or, to be precise, that there will not be more than 1,000 fatalities over the 10,000 years following repository closure.

This policy of controlled releases lacks political appeal, to say the very least. But there are other problems too. Viewed simply in terms of comparative risk management, the policy is defensible enough. Every day people are accepting greater risks than those a waste repository would impose, often arguably for benefits less than or no greater than the benefits from nuclear energy.

But the existing policy can, I submit, be greatly improved upon and at a big savings in money, technical trouble, and political expense. The present policy makes the siting, licensing, and development of repositories extremely difficult. The site must be thoroughly investigated, or "characterized," and its performance assessed by predictive models extending over the 10,000 years of hazard. From this exercise those in charge must convince peer reviewers and regulators that releases will never violate the standards.

The US Department of Energy is now experiencing growing frustrations at Yucca Mountain, its candidate repository site in volcanic tuff at the southwest edge of the Nevada Test Site. Site characterization is supposed to be completed by 1995, when under the schedule, licensing is to start. But in the view of many scientists, convincing performance modeling may be all but impossible. Waste would be emplaced in relatively dry rock high above the water table. Although this is favorable to waste isolation, the geology of the site is complex and the gathering of relevant hydrologic data extraordinarily difficult.

The problem at Yucca Mountain moreover is generic.[6] The geology of continental land masses is such that discontinuities are more the rule than the exception. Virtually every site investigated for a repository has presented problems and surprises. The deep seabed, by contrast, may offer some very large, homogeneous, and easily characterized sites that are suitable for waste isolation.[7] This we know from the excellent program of international research from which the United States abruptly and unaccountably withdrew in 1986. Work on subseabed disposal should be continued and revitalized. But this option is, at best, one for the long term,

because it is dependent on agreement by the world community that part of the global commons should be used for nuclear waste isolation.

The only relatively near-term option is deep geologic disposal on land. If nuclear power is to soon peak and then decline, only a few repositories will need to be built and licensed around the world. Given such circumstances, it might be possible to muddle through despite the problems presented by the controlled-release policy. But a large expansion of nuclear power would create a need for numerous repositories unless revolutionary changes in nuclear-fuel-cycle technology drastically reduced the amount of waste generated.

Viewed in this perspective, mastery of civil nuclear technology will not be complete until the complexity and uncertainty inherent in geologic isolation is compensated for in a manner that is convincingly robust. The thing to do, I am persuaded, is to take advantage of recent advances in the materials sciences by encapsulating the waste in a canister that can be expected to remain intact over the entire 10,000 year period of hazard. This would be the new philosophy or goal of "zero release," one that would not be realizable in a strict literal sense but that very likely could be approximated. The US initiative I contemplate would include several important program components, some of which would require action by Congress. Also, most would be directed by the Department of Energy, but with Soviet and other foreign participation encouraged. Part of the program, however, could be under international auspices.

This is what I have in mind:

- The Yucca Mountain project would be recast in an experimental mode. The present schedule would be put aside, with licensing deferred until a long-lived waste canister is available to provide extra assurance that the overall containment system will meet present regulatory standards—and then some. Indeed, I repeat, the goal would be that of essentially zero release. The project would include a Test and Evaluation Facility where in-situ testing would be done, a thousand feet below ground at the repository horizon, to define the conditions under which canisters would have to remain thermodynamically stable over time. The findings could have a crucial bearing on choice of canister materials and design. Some 100 tons of spent fuel, perhaps more, would be retrievably emplaced as part of the experiment.
- A variety of other potential sites and host geologies within the Basin and Range Province would be investigated, drawing on existing literature and using exploratory techniques that can be applied at the surface. Again, a major aim would be defining the conditions relevant to choice of canister materials and design.
- Materials scientists around the world would be invited to submit research and development proposals. Probably figuring large in such work would be the new generation of ceramic materials now under development. They offer greater promise of thermodynamic stability than metals and show a tensile strength and resistance to fracture that have not been characteristic of ceramics in the past.[8]
- The International Atomic Energy Agency would establish a working group to encourage and coordinate the research done in various countries to develop robust, long-lived canisters.

Ultimately, the Department of Energy would invite industry to compete for the contract to make the canisters for the spent fuel and high-level waste destined to go into the first repository, whether at Yucca Mountain or elsewhere. A key condition would be that the plant manufacturing these canisters must be in southern Nevada. This would be justified in part in the name of the economic conversion that should accompany any treaty stopping or drastically reducing the testing of nuclear weapons. I'm told that, taken

overall, canister manufacturing and waste encapsulation would be a sophisticated and demanding enterprise that might offer significant high-tech industrial spin-offs.[9]

Another measure that could find part of its justification in economic conversion would be to choose the Nevada Test Site for DOE's long proposed but still homeless monitored retrievable storage (MRS) project.

Admittedly, to have this controversial facility for spent fuel from US power reactors co-located with the Yucca Mountain project would be anathema to Nevada political leaders. They bitterly oppose any and all plans to dispose of nuclear waste in their state, doing so even as they continue to view weapons testing as an acceptable and even desirable activity.

There is indeed intense controversy over nuclear power and nuclear waste in both the United States and the Soviet Union. Only this past June, more than 500 witnesses lined up at a DOE hearing right here in Santa Fe to protest plans to open the Waste Isolation Pilot Plant (WIPP), the repository at Carlsbad for transuranic wastes generated in weapons production. Since Chernobyl, moreover, protests against local reactor projects have been heard over much of the Soviet Union, from Lithuania, Byelorussia, and the Ukraine to Georgia, Armenia, and Azerbaijan.[10]

But it is my view that in a larger political sense the best chance of changing public attitudes in this country and around the world toward nuclear power and nuclear waste disposal will lie in seeing that, wherever possible, efforts to master the problems of civil fission energy are coupled with the efforts now going on to reduce the threat of nuclear weapons.

This proposition derives partly from the fact that the most frightful thing about the atom is the bomb. But it also derives from a belief that many of the people who worry about nuclear power will eventually think better of it if cutbacks in weapons activity and greater mastery of the civil atom are shown to be complementary.

Here a good start can be made, I believe, by the nuclear waste initiatives which I am suggesting that the United States and the USSR undertake at their weapons test sites in Nevada and Kazakhstan.

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DESIGNING EFFECTIVE PROTECTION AGAINST THREATS AT NUCLEAR FACILITIES

by

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INTRODUCTION

To build confidence in the viability of nuclear fission power, the public and governmental agencies must be assured that facilities handling nuclear material are adequately protected against a spectrum of hypothesized threats and their potential consequences. Not only must the protection be adequate, but it must also be perceived to be adequate by the public. Moreover, facilities must demonstrate that these systems are implemented in a cost-effective manner. No matter what reactor design or fuel cycle is used, certain of these threats must be considered, e.g., earthquakes, and therefore it is important that methods be developed to ensure adequacy of protection. Such threats are being studied on an international basis with guidance being developed by the International Atomic Energy Agency (IAEA), and confidence in their use is being built through information exchange at various bi-lateral and multi-lateral conferences.

As an example of how such threats are considered, we will focus on two types of threats: the threat of a malevolent act, such as theft or sabotage, and the threat from natural or man-made hazards, such as earthquakes and fires. The former threat is, of course, a safeguards concern, whereas the latter is a safety issue. This paper is divided into two parts. In the first we describe the analytic tools we're developing to assist in designing cost-effective protection against malevolent acts. In the second part we provide example approaches for performing risk assessments for external events.

PROTECTION AGAINST MALEVOLENT ACTS

One of the primary malevolent acts of concern is the theft or diversion of fissile material from nuclear reactors and fuel cycle facilities. Usually the concern is focused on quantities of material that might be used to construct an improvised nuclear device (IND) or that otherwise can be dispersed in the environment. Materials considered include plutonium or enriched uranium. This restricts the threat to facilities that handle large quantities of such nuclear material.

Another type of malevolent act, sabotage, is a more general concern and must be considered wherever radioactive materials are stored or where the loss of production capability may be a concern. These threats are often referred to as radiological and industrial sabotage respectively and are of major concern at any reactor or fuel-cycle facility.

Consequences resulting from these threats can be severe and may affect public health and safety, national security, and the economy. For this reason a large body of domestic regulations promulgated

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by the Nuclear Regulatory Commission (NRC) and international reviews through the IAEA have been implemented to protect against these types of threats. Similarly the Department of Energy (DOE) is responsible for establishing orders and guidance for their facilities.

To assist in the design of safeguards systems and to ensure the adequacy of protection, probabilistic-based systems analysis tools have been developed to perform vulnerability assessments and cost-benefit studies concerning these threats. These tools allow a user to assess the vulnerability of his/her facilities to such threats, to identify the safeguards strength and weaknesses, and to determine if upgrades are needed and, if so, determine the most cost-effective design approach. Such tools have been used to evaluate the effectiveness of protection systems at most DOE facilities, to identify upgrades, and to analyze the cost-effectiveness of these upgrades prior to implementation. The tools will also be used to assure that these facilities comply with the new DOE Order concerning Material Control and Accountability (DOE order 5633.3).

Threat assessments must be made taking into account a spectrum of threats, such as those posed by demonstrators, criminals, terrorists, foreign governments, and employees (insiders). Tools now available include ET (Al-Ayat, 1986) for evaluating effectiveness against the insider threat, MI$ER (Al-Ayat, 1987) for conducting cost-effective analysis, and ASSESS (Al-Ayat, 1989), for conducting an integrated evaluation against insiders, outsiders, and insider/outsider collusion. The latter, ASSESS, is being developed jointly with Sandia National Laboratories under the sponsorship of DOE. More than 400 safeguards specialists have been trained to use ET and MI$ER, and training will begin on the use of ASSESS next year.

Effectiveness evaluation combines information about the facility safeguards, target characteristics, and adversary descriptions with an extensive database of safeguards defeat methods and their probabilities. These inputs are used to determine success probabilities for different types of adversaries and scenarios. Knowing these success probabilities, one can determine where upgrades are needed. In MI$ER, effectiveness of upgrades, as measured by the extent to which they affect the probability of detecting and interrupting a theft, diversion, or sabotage attempt, is then weighed against incremental cost to prioritize upgrades and to determine the most cost-effective solution.

RISK ASSESSMENT FOR EXTERNAL EVENTS

Another type of threat to nuclear facilities results from natural phenomena and man-made hazards external to the facility. Such threats are called external events. These include earthquakes, fires, floods, high winds, and tornadoes among others. Risk assessments have shown that these hazards can be key contributors to risk from nuclear facilities. However, quantification of this risk can be difficult because of the lack of data to substantiate estimates of event probabilities, particularly the severe events that are most damaging to the plant. Also external events affect the entire facility and thus defeat the redundancy designed in to assure successful recovery from the event.

Accordingly, the concern for safety at nuclear facilities has led to excessively conservative designs that are costly and impose counterproductive design constraints. An example of this is the restraints that were put on piping in nuclear power plants in the 1970s to protect against an earthquake. These constraints are now being removed to allow for thermal expansion of the piping. The latter was found to be the greater hazard. Thus money was wasted both in putting in the pipe restraints and later in removing them.

Since traditional, deterministic design methods used to guard against external hazards result in excess conservatisms, probabilistic techniques were employed to better balance the design (Cummings, 1986).

In general these probabilistic techniques give best-estimate values for design parameters with a statement about the uncertainty in the estimate. Thus the designer can better judge what the true risk contributors are, stripped of their conservatisms, and balance out the design accordingly. These risk-assessment methods require as input an estimate of the hazard frequency, the response of the plant and equipment to the hazard, estimates of the failures caused by the response, and a plant logic model to determine what the consequences of the failures are. The output of the risk assessment is the probability of various plant damage states, including those leading to radioactive release and system and component failure probabilities. From these results dominant contributors to risk can be determined and effort focused on fixing the most important risk contributors. Unfortunately, these probabilistic risk-assessment methods can be very expensive and are difficult for the designer to use; hence efforts are under way to arrive at more simplified approaches.

One such simplified approach is the Seismic Margin Assessment Method which has been developed for the NRC by LLNL (Cummings, 1988) and for the nuclear industry by the Electric Power Research Institute (EPRI, 1988). This approach uses the results from risk assessments and design experience to focus the analysis on only those components that have both a low seismic capacity and whose failure has risk significance. To start the assessment, an earthquake review level is selected whose intensity is comfortably above the intensity level (peak ground acceleration) for which the plant was designed. Teams of systems and structural/equipment analysts are then assembled to decide which systems and components need to be reviewed. They do this screening based on plant visits (walkdowns) and guidance based on previous experience. Those components not screened out of the analysis are assigned a lower-bound capacity value which when incorporated into the plant logic model provides a lower bound capacity value for the plant. This value is then compared to the earthquake review level. If the plant capacity is found to exceed the review level, then the plant is defined as having adequate safety margin concerning the seismic hazard at the site. If not, then weak links have been identified to focus on any upgrades deemed necessary. This method has been successfully demonstrated on the Maine Yankee Atomic Power Station.

Such simplified methods are most useful for existing facilities but can also be helpful in assessing new designs, depending on the experience base available. Other such focused and cost-effective methods are being developed for other external events.

CONCLUSION

Designing protection against the threat spectrum to facilities handling nuclear material in a cost-effective and demonstrable manner is becoming increasingly important, especially in light of increasing costs and decreasing public confidence in nuclear power. This is clearly true for the current generation of plants but will also be true for the new generation, at least until their operating history demonstrates adequate threat protection.

In this presentation, we have provided a brief description of how designing and upgrading to protect against threats can be done for two types of threats, malevolent acts and earthquakes. These methods are currently being used on existing nuclear facilities and are being extended to address non-nuclear facilities and other threats. The technology is being transferred to users both internationally and in government-owned or licensed facilities so that those most intimate with the problem can determine the appropriate solution. Use of such techniques in the review, licensing, and upgrade process is essential if we are to bring into line the cost of nuclear power and resolve outstanding issues relating to safeguards and safety issues.

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A CLEANER ENVIRONMENT WITH NUCLEAR HEATING

by

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INTRODUCTION

In Canada, Scandinavia and Central Europe, about 30 percent of the primary energy consumed is used for heating buildings.[1] District heating systems provide greater fuel economy, better pollution control and more flexibility to use a variety of fuels, including municipal waste and bio-mass.

Extensive combustion of hydrocarbons in densely populated urban areas pollutes the air and produces adverse health effects. Furthermore, the acid rain damages the surrounding environment, affecting plants, water and wildlife. The gas emissions also contribute to the greenhouse effect, which is becoming a matter of increasing global concern.

Although conservation and solar heating can reduce the demand for fossil energy (with its associated pollution), there is a limit to what can be achieved at a reasonable cost. As living standards improved people will insist on a reasonable level of comfort in their homes. For those living in northern localities, the reliable supply of adequate heat is a matter of survival during the long, bitter cold winter. Development of the far north depends on the availability of affordable heating that will not damage the fragile Arctic environment.

Atomic Energy of Canada recognized these problems and initiated a program to develop and apply nuclear technology, specifically for district heating. We hoped people would recognize the damage being caused by burning fossil fuels and turn increasingly to the better technology of nuclear heating. We are proceeding to demonstrate the advantages it offers and the low risks.

Our program for the development of nuclear district-heating addresses the special requirements of locating such a facility in an urban area. Some of the abnormal events, of concern in large nuclear-electric plants, can be accommodated at low cost in a small district heating unit because the performance requirements are different. For example, high temperature and rapid load-following are not needed for heating buildings, so a greatly simplified design can be used.

We studied the inherently safe characteristics of our 20 kW SLOWPOKE research reactors, located in downtown areas. We determined to what degree they could be retained as the power is uprated. A 2 000 kW prototype is being commissioned at Whiteshell Research Centre, and a 10 000 kW design has been prepared that is adequate to heat a building complex of 1500 apartments. The projected cost of the heat is competitive with oil heating in many parts of Canada, and a site has been selected for construction of this commercial-size unit.

The design objectives we set were:

- cost-competitive with oil heating,
- very safe,
- very reliable, and

- very low releases.

I cannot release any technical details about the design, but I can mention the following features:

- high quality design,
- fault-tolerant computer system for automatic plant control and remote monitoring,
- two diverse safety shutdown systems,
- very slow rate of power adjustments,
- low temperature operation (up to 100°C),
- atmospheric pressure operation,
- large heat sink for decay-heat removal,
- natural circulation flow (convection) in primary circuit,
- tolerant of, and protected from, abnormal events, internal and external,
- conservative fuel power rating,
- long fuel life,
- low fuel cost,
- low capital cost,
- low operating cost
- modular design for rapid construction and commissioning, and
- compatible with hot-water district heating plants.

The concept is shown in Figure 1.

The 1/2 m^3 reactor is located in a 350 m^3 water pool. The water provides the necessary shielding and has a large heat capacity. The reactor shuts down automatically when the district heating load is interrupted. Even without operator action, the pool will not reach the 100°C boiling temperature for days. At this point, the plant could still sit unattended for many months without the fuel ever overheating.

The fuel has a low enrichment and will last for 5 years of operation. Absorber pins are removed from the core during a short maintenance shutdown every summer. A dual, fault-tolerant computer system is used to regulate the power level very slowly to match changes in the load demand. The reactor pool is in a closed steel tank that is, in turn, enclosed by a concrete vessel. An intermediate, pumped loop isolates the primary circuit from the district heat-distribution system. Licensing of the design is presently underway with our Atomic Energy Control Board.

An agreement has been signed with Hungary for cooperation in using this nuclear heating unit in large district heating plants. A joint study is underway on localizing a part of the design and the construction work, including supply of the fuel. After the first unit is licensed and built in Canada, we plan to enter into joint ventures to provide nuclear heating units in Europe and the Far East, to help provide secure energy without pollution.

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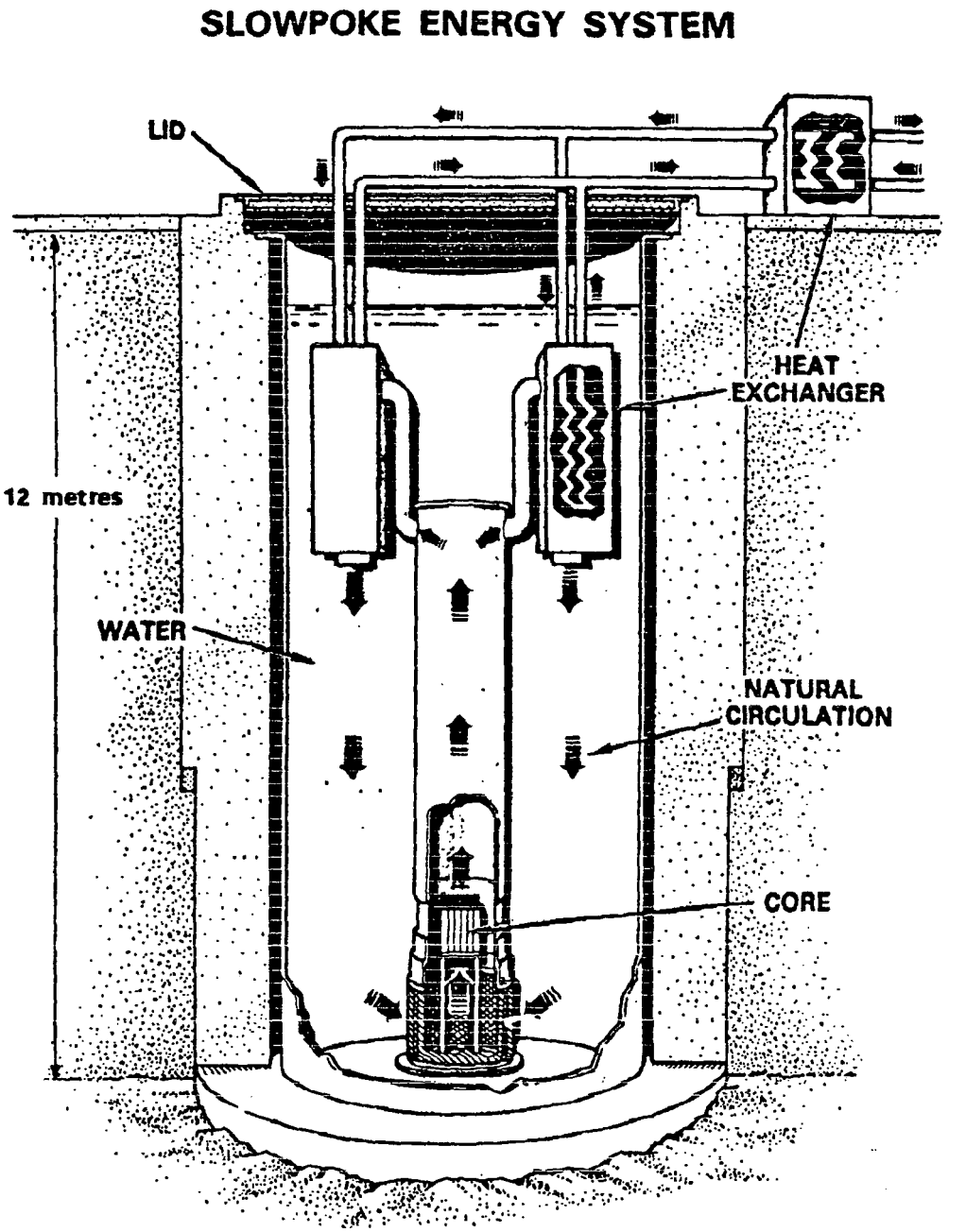


Figure 1. Schematic diagram of the SLOWPOKE Energy Concept.

ENVIRONMENTAL COLLABORATIONS IN THE USE OF ACCELERATOR MASS SPECTROMETRY

by

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INTRODUCTION

Accelerator Mass Spectrometry (hereafter AMS) is a technique for analyzing extremely low levels of radionuclides. The technique was first demonstrated slightly over a decade ago at three laboratories virtually simultaneously.[1-3] In the usual implementation of this analytical technique, a beam of ions containing both the rare isotope of interest and the more abundant stable isotopes is accelerated to high energy using a tandem Van de Graaff accelerator. A combination of electron stripping at high velocities (which destroys all molecular species) and redundant magnetic, electrostatic and energy analysis allows one to measure rare to stable isotope ratios as low as $1{:}10^{16}$. The layout of the system implemented at LLNL is shown in Fig. 1.

As the rare isotopes are identified by particle counting, rather than by waiting for their decay, one may assay small samples for very low concentrations of long-lived nuclides. This ability to do single atom detection independent of the half-life of the isotope has allowed AMS to extend the applicability of many research areas that use isotopic tracers. At present, there are approximately 20 accelerator facilities world-wide where such measurements are possible. In general, each accelerator has other missions in nuclear research, making available only a limited amount of time for AMS analyses. There are two dedicated facilities in North America, one at the University of Toronto and one at the University of Arizona, specializing primarily in radiocarbon dating.

EXISTING APPLICATIONS OF AMS

The best developed applications of AMS are in the fields of archaeology, geophysics and cosmochemistry. An excellent review of the technology and applications in the field to date has been given recently by Elmore and Phillips.[4] The isotopes most often analyzed by AMS are those generated by cosmic rays and their secondaries in the atmosphere and upper few meters of the earth's surface. These cosmogenic isotopes include ^{10}Be, ^{14}C, ^{26}Al, ^{36}Cl, ^{41}Ca and ^{129}I.

The half lives of these isotopes range from 5 730 years for ^{14}C to 16 000 000 years for ^{129}I. Concentrations of these isotopes present at the earth's surface range from one part in 10^8 to one part in 10^{16} of the stable isotopes. While the best known and most used application of a cosmogenic isotope is radiocarbon dating of human artifacts for archaeological studies, other applications are possible as well. Because their lifetimes are relatively short on geological time scales and because their concentrations are constantly replenished at the surface of the earth, these isotopes make excellent tracers for a variety of geochemical and geophysical studies. Because the isotopic concentration begins to decrease with the nuclear half life when material is removed from the source at the surface of the earth, both the path of an element through its

natural cycle and the flow rate can be determined by measuring the ratio of the rare to abundant isotope(s). A set of excellent tracers and clocks for the study of near-term environmental change is thus available with AMS analysis.

Examples of specific applications are easily given. Measurement of the ^{14}C fraction in ocean water is used to infer details of interchange at the ocean-atmosphere interface. Similar measurements are used to date the age of water circulating in the deep ocean currents. As an example of human effects, measurement of ^{14}C fraction in short-lived molecular species such as CO can be used to determine the fractions resulting from burning fossil and organic materials in regions impacted by pollution. The ^{36}Cl in dissolved chlorides may be used to study the details of infiltration and percolation in the movement of ground waters and, in special cases, to date them. Erosion processes may be inferred from ^{10}Be records in soil washed down from higher elevations, polar precipitation rates may be deduced from ^{10}Be and ^{36}Cl retained in ice cores, and melting and retreat of glacial ice can be dated by measuring ^{10}Be, ^{26}Al and ^{36}Cl produced in rocks left on the tops of terminal and lateral moraines.

LLNL CAPABILITIES AND APPLICATIONS OF AMS

The Lawrence Livermore National Laboratory began building an AMS capability as part of a new nuclear technology laboratory in 1986.[5] The AMS beamline at the laboratory[6] was intended to be used in geoscience applications similar to those outlined above and for development of new tracers for use in underground testing. During construction of the laboratory, the Regents of the University of California chose to co-fund the spectrometer to provide access to this new tool for faculty members at the UC campuses, primarily for archaeological dating purposes. Subsequent to UC joining the venture, it became clear that much broader application of the tool was possible. Experiments in the geosciences and environmental sciences are being planned and executed with staff from a wide range of the UC campuses.

Assessment of possible uses of AMS in new fields resulted in an internally funded initiative at LLNL to explore applications in biomedical, clinical and environmental research. This initiative was made possible by the Department of Energy regulations that allow the national laboratories to spend up to 2% of their direct programmatic funding on internally selected research, chosen to have scientific quality and being likely to yield new program assignments or major improvement in existing program capability. The focus of the initial investigations is to apply AMS to research areas in which added or induced isotopic tags, not just naturally occurring ones, can provide new investigative tools.

Several experiments which apply those same isotopes which are of geophysical interest to biomedical problems are now in progress or preparation. While the lifetimes of these nuclides are short on geological timescales, they are long on biological timescales. The resulting low-delivered-dose, combined with low natural abundance in the biosphere and the very high sensitivity for detection possible with AMS, suggests several new uses in biological and clinical investigations. Higher sensitivity than available with present tracer techniques, lower dose delivered to patient or other host, or simply reduced costs because isotope levels are lower are all possible results of designing experiments that exploit the sensitivity of AMS. Experiments include locating adducts on DNA produced by mutagenic chemicals, tracing mutagen production pathways in cooking, and validating the Hiroshima neutron dosimetry by detecting ^{36}Cl induced in building materials. Jointly with collaborators at the University of California, San Francisco, we will explore techniques for measuring calcium inventories and transport in pediatric, geriatric and zero-gravity medicine.

In addition to the scientific component of the initiative, there was a technological one as well. The utility of any analytical technique is as much influenced by its cost as by its scientific value, especially if it is to be deployed on the large scale typical of global environmental or applied medical investigations. We therefore included as part of our planning the development of hardware and software systems required to automate the spectrometer and portions of the sample preparation process. We anticipated that automation would be necessary if real clinical applicability was to be demonstrated. Operation in an automated mode is expected to be demonstrated in the next year. The goal of this effort is a spectrometer system capable of 5 000 to 10 000 sample measurements per year, operating in a basically unattended mode.

Two experiments that affect global environmental issues would benefit greatly from a high throughput AMS analytical system. At present, a dedicated AMS laboratory is to be built at Woods Hole to perform radiocarbon measurements of sea water samples for the World Ocean Circulation Experiment (WOCE). Throughput expected for this NSF supported laboratory is 5 000 samples per year. This single experiment will fully occupy the laboratory for five years. Equivalent demand could easily be generated by attempting to resolve uncertainties in the global carbon budget by measuring the quantity and age of dissolved organic carbon contained in soils and in waters on continents. An experiment under consideration for proposal to the International Geosphere-Biosphere Project (IGBP) will measure atmospheric mixing processes by tracking the transport of stable and radioactive isotope.[5] Measurement of ^{210}Pb resulting from radon decay would be used to determine mixing of air as a function of height and distance from the continental margins out over the ocean. Measurement of ^{7}Be, ^{10}Be and ^{36}Cl as a function of height above the ground would be used to determine the rates of aerosol exchange between stratosphere and troposphere. The details of a pilot experiment to determine sensitivities and sample acquisition requirements are under discussion at present. Implementation of such measurements on a scale large enough to produce sufficient data to affect normalization of global circulation models would require simultaneous air sampling flights along many latitudes in one or both hemispheres and much greater analysis capability than exists at present. Large numbers of commercial aircraft would have to be equipped with intelligent semi-autonomous sampling systems to execute such a program.

UC FOCUS FOR COLLABORATIVE PROGRAMS

The University of California System has the capability to serve as a focus for an extended international program to develop AMS as a tool for large scale environmental measurements. The System has the ability to create Multi-campus Research Units (MRUs) that bring together campus and national laboratory collaborators to pursue disciplinary and cross-disciplinary research. Many campus staff are already involved in experiments with the present AMS capability at LLNL; extension to a larger community would be fairly simple.

Most of the science and a fair fraction of the art of isotopic studies with AMS are in the sample selection and preparation process. Technologies for this portion of the work involve mostly physical chemistry and are readily transferred to any participating nation or agency. The accelerator and spectrometer technologies may be similarly transferred. Because sample preparation takes considerably more time than analysis on the accelerator, multiple sample preparation laboratories can support a single accelerator facility. A participant may join a sampling program by investing in a relatively inexpensive preparation laboratory. Because in any large scale sampling program the sample selection and preparation work would be under the control of local experimenters, international measurements on a large scale can be conducted without the concerns

about economic or intelligence use of the data that have occurred in oceanography and other geophysics programs.

Growth in demand for AMS capability will likely result from demonstration of novel clinical and new environmental applications, coupled with the positive economic effect of lowering the per-sample cost of an analysis by automation. We have taken steps to respond to such demand by beginning the design of a new dedicated facility for AMS measurements. Such a facility could be built on UC lands outside the LLNL perimeter fence. Construction could be very rapid as we would simply clone systems from our present facility, including the unshielded building design that suffices for this accelerator operating mode. To support this option, we have acquired two accelerators and the large magnets for the spectrometers. The decision to pursue such a project will be made within the next year.

ACKNOWLEDGEMENTS

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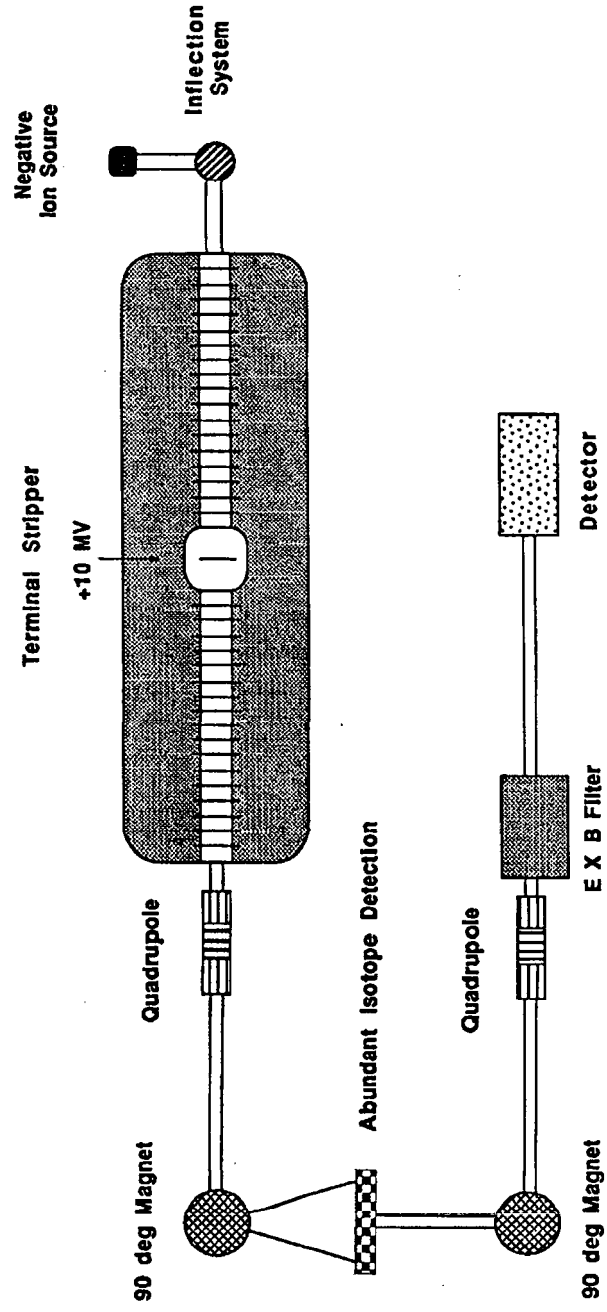


Fig. 1. Cartoon of the LLNL system hardware.

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REDUCING THE DEVASTATING EFFECTS OF CATACLYSMIC EVENTS: COOPERATION

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ABSTRACT

Natural calamities, including earthquakes, land sinkings, volcanos, floods, tsunamis, hurricanes, avalanches, lightnings, forest fires, are discussed. Their devastating effects can be alleviated by cooperative efforts, sometimes international, among all concerned. The successful earthquake management of the Haicheng event is discussed as an example. Now we have environmental calamities, including erosion floods, dam failures, acid rain, ozone depletion, and the global greenhouse effect. There are empirical and theoretical questions about whether the greenhouse effect leads to global warming or polar ice melting. The warming prediction was based on model calculation with an incorrect boundary condition. When corrected with the right boundary condition, the models predict ice melting. The same is borne out in independent static and dynamic theories.

Thus, there will be no greenhouse warming, only a sea level rise of up to 200 feet, which is much worse. The only way out is replacing fossil fuels by nuclear power. The nuclear fear is analyzed in terms of the Don Quixote syndrome and Laplace dictum. The lessons of Three Mile Island and Chernobyl actually strengthen the case of nuclear safety. New reactor technology and design will make it even safer.

After 250 years of studying the history of the earth, geologists are now able to show that it is nothing but a long series of gradual changes and violent events. What was true in the past will remain so in the future, and cataclysms will occur again and again.

Earthquakes, land subsidence and volcanic eruptions; flood and drought; the tsunami, tropical cyclones and avalanches; lightning and forest fires; have occurred ever since mountains, oceans, rivers, atmosphere, and icesheets have been on the earth, and they will continue to happen.

EARTHQUAKES AND LAND SINKINGS

Although California is where the quake action is mostly confined in the US, China and Japan are much more seismically active. China suffered one of the worst disasters in earthquake history, the Tangshan earthquake of 28 July, 1976. A catastrophic earthquake of magnitude 7.8 at 3:43 a.m. struck Tangshan, a city of about a million inhabitants located 150 km east of Beijing. Ninety-eight percent of the residential buildings and 90% of the industrial structures in the city were completely destroyed. Loss of life from the earthquake was estimated by the government to be 240 000, and 164 000 persons were severely injured.

Numerous land sinkings have been recorded in California where vast amounts of water are withdrawn for irrigation and for domestic and industrial uses. From 1925 to 1977, 20 billion cubic meters of earth volume have disappeared, caused by the extraction of about 70 billion cubic meters of groundwater in the

San Joaquin Valley. In Japan a sinking area totals 9,520 sq. km, about 12% of the inhabitable land of the nation, according to a survey in 1981. The city of Shanghai, China, sank 2.63 m between 1921 and 1965.

VOLCANOS AND FLOODS

Volcanic activities can be of two types, the effusive, which is typical of the mid-ocean islands such as Hawaii, or the explosive, which is predominantly confined to the island arcs (the lesser Antilles, the Aleutians, etc.). An explosive volcano is capable of destroying an area 500 000 sq. km. in a matter of days; the land is made unfit for any agricultural use for a long period.

Flood and drought were the most common catastrophes in history. The flood of the Yellow River (Hwang Ho) in China in 1931 caused 4 million casualties and during the flood in East Pakistan in 1970, one million people perished. Many major drought episodes have affected China, accompanied by enormous famine and loss of life of up to 10 millions, such as in 1877. Drought often accelerates the deterioration of arid and semi-arid lands or desertification, as has been the case in Africa.

TSUNAMI, HURRICANES, AND AVALANCHES

The tsunami is a series of high ocean waves of very great extent and period generated by impulsive disturbances of the earth's crust. Large earthquakes with epicenters under the ocean or near it but below the ocean floor are the cause of the most catastrophic tsunami. Although infrequent, tsunami are among the most terrifying and complex physical phenomena and have been responsible for great loss of life and property.

Tropical storms are severe cyclonic disturbances of the atmosphere that form in the low latitudes—between 5 and 30 degrees in both the northern and southern hemispheres. These storms are cyclonic spirals, the wind forming a vortex that, as a result of the earth's rotation, turns clockwise in the southern and counterclockwise in the northern hemisphere. The vortex of air spirals inwards to the center where the pressure is at a minimum. This area, known as the eye of the storm, contains only light winds, or may even be calm. Around the eye explosive cloud growth takes place as warm, moist tropical air rushes upwards to heights of 12 000 meters or more. This is the region of maximum winds which may exceed 270 km per hour. If the winds in such a cyclonic spiral exceed 120 km per hour, the storm is called a "hurricane" in the western Atlantic, a "typhoon" in the western pacific, or sometimes just a "cyclone" in the Indian Ocean. The toll of the cyclone that struck Bangladesh, India, in November 1970, was over 400 000, an amount that is almost unimaginable. It has been estimated that in an average year, eighty to a hundred tropical cyclones form over the world's oceans. In addition to destroying human lives, they also destroy the economic resources of the countries affected by $6 to $7 billion per year. The 20th-century hurricane damage in the US alone exceeded $12 billion before 1986.

Avalanches may range from a small, inoffensive flow to a huge, destructive and lethal discharge consisting of up to 100 million cubic meters of moving snow with an impact pressure that may be anything up to 100 tons per sq. m. Once set in motion, the powdery fresh snow mixes with the air and flows like a heavy gas. It may reach a very high velocity, up to 300 km/hr, creating a smothering blanket in its proximity; it fills the ambient atmosphere and spreads into houses.

LIGHTNINGS AND FOREST FIRES

With an average of 50 million cloud-to-ground flashes striking the US each year, lightning is among the nation's most severe weather hazards. Basic research concerns the interactions of an individual lightning flash, the damage caused by the large current that flows in the return stroke of a flash, the resulting shock wave, and protection against lightning.

The forest fire is common in many countries in the world. It is also an important factor in the earth's ecology.

NATURAL AND HUMAN-MADE DISASTERS

Confronted by the violent forces of Nature, mankind is still not strong enough to safeguard against all kinds of natural hazards, besides so many man-made risks. It is true, however, that modern science and technology have liberated mankind from the absolute powerlessness that our forefathers experienced. This is particularly so for developed nations. Yet, disasters plague the entire world. They do not stop at political boundaries.

Scientists agree that epochs characterized by unusual activities have taken place, such as periods of violent volcanism, tectonic disturbances, as well as severe climate changes. These processes have not always been identified with the concept of disaster because the presence of human beings, in large numbers, and eventually in structured societies, is what makes a natural process a disaster. As the world population increases and modern civilization spreads, the conflict between the earth and mankind is not likely to abate, but rather develops on a much wider scale. The depletion of natural resources, coupled with a general environmental deterioration, reflects mankind's relentless encroachment on nature, leading to a widespread environmental crisis. Human activities cause severe stresses on nature, as manifested in massive deforestation, uncontrolled soil erosion, unlimited withdrawal of groundwater and the pumping of crude oil and natural gas, and the various forms of pollution that taint the atmosphere, the hydrosphere, and the biosphere.

WORLD COOPERATION NEEDED

It is clear that the scope of most natural disasters often reaches far beyond the political boundaries of a country and affects far beyond the capabilities of developing nations to deal effectively with them.

The world must recognize the pressing need for studying the causes and effects of disasters, their nonlocal nature, and the staggering impact they have on mankind, especially on the developing nations. Although it is sadly evident that no magic wand can quickly solve the problems we are facing, these facts should not discourage the continued efforts to secure knowledge and develop means to offer all people a life without needless suffering.

The only way to reduce our vulnerability to Nature's violent forces is cooperation between the scientists who study the hazard, the general public that is exposed to the risk, the media that divulge information, and the administrative authorities who carry out necessary measures. The effort must be international, since the problem facing us is a confrontation of Nature and Mankind.

COOPERATION IN EARTHQUAKE MANAGEMENT

A salutary example of cooperation for crisis management is the prediction of and preparation for impending earthquakes as carried out in China. With a long history of such events and the accumulation of folklores, some form of prediction has been in existence since early times without the benefit of modern geological science. The meteorological (strange light phenomena) and biological (unusual animal behaviors) events preceding the quake sound mysterious, but many are scientifically true and can be used to supplement geological findings. Thus, earthquake prediction is not merely the prerogative of the seismologists; it involves collaboration among many fields. Monitoring the change of radon content in water involves radiochemists. But even school children are enlisted to monitor changes in well-water level by using simple instruments (weight and line) on their way to school. The statistics collected by all children provide a clear picture of tectonic changes. Once a reliable prediction has been arrived at, the administrative authority will have to direct the evacuation of the population from the dangerous areas. The cooperation of the whole community and the scientific personnel is at the base of the entire program of crisis management.

Modern earthquake-prediction research first appeared in Japan in 1962, then in the US in 1965. After experiencing severe earthquakes of magnitude 6.8 and 7.2 at Xingtai (about 300 km southwest of Beijing) in March 1966, China established a national earthquake program. Earthquake prediction was given high priority and wide publicity.

SUCCESS IN HAICHENG QUAKE

Haicheng (population about 100 000) in Liaoning Province was struck by an earthquake of magnitude 7.3 at 7:36 p.m. on February 4, 1975. Scientists correctly predicted it beforehand and successful evacuation was carried out. Before 1970 the State Seismological Bureau identified Liaoning as a high-risk area from a long-term prediction. Geological and tectonic surveys, long-base-line measurement of tilt and gravity, and geomagnetic surveys were carried out. Between 1970 and 1974, an additional 14 seismological observatories were established in the area.

In June 1974, on the basis of a deformation study, an earthquake of magnitude 6 was predicted for the first half of 1975. On January 30, 1975, the ground tilt at Shenyang Seismological Observatory suddenly changed its direction from SE to SW. Beginning on February 1, an increase in the number of microearthquakes occurred in the Yingkou and Haicheng area.

Then on February 4, continuing earthquakes of magnitudes 4.3 and 4.7 suddenly decreased at noon. At 2 p.m. a general alarm was issued and inhabitants were moved to an evacuation camp. The main shock of magnitude 7.3 occurred at 7:36 p.m. There was little loss of life.

In the past the notion of natural disaster included not only cataclysmic events of the earth but also slowly developing events over a limited period, such as pestilence. The medieval plague was a disaster in every sense of the word, including the point of view of from crisis management. Thus, the AIDS epidemic should be included in the future.

EROSION, FLOOD AND DAM FAILURE

With the increase in human tampering with nature, we can foresee, in the future, natural disasters that are not "the will of God" but are of human origin. And both the cataclysmic and slowly developing kinds may be present.

Floods used to be an "act of God." But with accelerated soil erosion, the frequency and magnitude of floods will undoubtedly magnify. Dam building has been a fashionable enterprise for a century. With the benefits of flood control, hydroelectric generation, facilitation of navigation, recreational and real estate developments, it was considered a many-faceted blessing. Now that many of the dams are aging, major dam breaks with loss of life are happening once or twice a year. Statistics have shown that dam risks are greater than that of nuclear power failures. With increased aging, the problem will be more serious as time goes on. It has been said that if the dam above Los Angeles should fail, the casualties could be over 100 000. Dam safety will be one of the major concerns in the future.

ACID RAIN AND OZONE DEPLETION

Two major environmental problems are the acid rain and ozone depletion, due respectively to the burning of soft coal and the use of fluorochlorocarbons in industries. These are man-made disasters but are of the slowly developing type. The new feature is that they involve a wide region that disregards national boundaries and may even be on a global scale. International and even global cooperation are necessary for effective control of these tendencies. Acid rain has been a sore spot in the international relations of the US and Canada–the sources of acid rain are in the US, but Canada reaps the harvest. It is an issue in the agenda of every summit between the two nations. The ozone-depletion problem has generated world attention. British Prime Minister Thatcher has called an international meeting on this issue.

GLOBAL GREENHOUSE EFFECT

Perhaps the most profound environmental problem is the global greenhouse effect. The accumulation of carbon dioxide and the other greenhouse gases in the atmosphere tends to trap solar energy near the surface of the earth. It is generally thought that this will cause a rise in temperature (the greenhouse warming). An increase of several degrees in the next century would have serious impact on climate, agriculture, forestry, fishery, economy, and demography. For example, the wheat belt will move from the fertile Midwest to the less productive Canada, causing serious agricultural and economic dislocation. A large number of studies of the meteorological changes and their consequences have been made and policy suggestions proposed.

Less attention has been paid to the possibility of melting the ice in the polar regions and the consequent rise of the ocean level. If all land ice melted, the ocean level would rise by 200 feet, inundating all coastal areas and affecting the habitat of more than one-half of the world's population. The consequences would be even more serious than those of global warming.

GLOBAL WARMING OR A RISING SEA LEVEL?

Empirical studies on the temperature trend in the past one hundred years are not conclusive. Whereas Hansen found an increase of 0.8° C in the period, another study by Hamson found no change at all and the previously noticed increase was attributed to the effect of urbanization. Other studies found much of the expected warming missing. On the other hand, evidence is accumulating for the melting of ice and a rising sea level. Satellite surveillance of Antarctic snow field indicates a receding of the coverage. The same is true in Alaska as measured by the date the last snow melts in Barrow, which decreased from mid-June in 1941 to late May in 1985. The ice in Lake Hoare in the Antarctica has thinned 2 meters in the past 10 years. In 1987 a gigantic iceber, designated B9 with a size three times that of Long Island broke off the Ross Iceshelf, indicating accelerated wasting of the Antarctic icesheet.

GLOBAL WARMING FROM CLIMATE-MODEL ERROR

Whereas empiricists can study both global warming and ice melting, theorists can entertain only one of the two, either global warming or ice melting, because the greenhouse heat can do only one or the other (or a compromise splitting). Climate models advocating global warming usually do not accept ice melting. However, these models usually use a boundary condition represented by an insulting wall that allowing temperature to increase to create greenhouse warming. But this condition is not realistic because the iceshelves fix the temperature at 0° C and it can never increase. The correct boundary condition should then be a conducting wall in contact with an infinite heat reservoir at 0° C (that is, the iceshelves). The models would then predict little global warming and mostly ice melting. Besides, the ice-melting theory can be developed in a static theory (neutral equilibrium theory) and independently in an ultimate dynamic theory, all leading to the same conclusion—a large splitting ratio 97:3 in favor of ice melting over global warming.

AN ICE CUBE IN WATER HAS NO WARMING, ONLY MELTING

While this conclusion is against the conventional wisdom of greenhouse warming, its validity is obvious by comparing the iceshelves-ocean system with a glass of ice water. Room heat can never warm the water above 0° C; it can only melt the ice cubes in the water. The splitting ratio would be 100:0. However, the ocean does not have a uniform temperature, which leads to a feedback effect, changing the splitting ratio to 97:3 as stated above.

All greenhouse models have ignored the existence and interaction of the cryosphere, leading to mistaken results that will remain invalid until the icesheets have completely melted 500 years later. Then greenhouse warming will commence, and climate, agriculture, forestry, fishery, economy, and demography will begin to change as predicted 500 years earlier. In the meantime, nothing will happen, and the climate models will be hard put to explain the double discrepancy: why the predicted warming did not appear to the extent expected and why the ocean level rose after all.

Once this fundamental point is cleared up, we can be relieved of the impending danger of global warming for 500 years. The only immediate worry is the rising sea level. The only symptomatic relief is the building of dikes to fend off the ocean, like the Dutch have done for centuries. The fundamental solution, of course, is a change of the energy source away from fossil fuels.

THE BIBLICAL FLOOD AND THE APOCALYPTIC FLOOD

Before discussing alternative fuels, some accompanying hazards may be mentioned in passing. As the icesheets were melting in the last ice age, scientists suspect that at one point the whole icesheet broke loose from the land and slid into the ocean in one piece, suddenly increasing the ocean level by a large amount in a short period. The same scientists have even related this to the Biblical flood at approximately the right time! If this should happen during the greenhouse melting of the Antarctic icesheet, we have reason to worry about the tsunami that will occur when this large solid mass is dumped into the ocean at high speed. The resulting tidal waves would sweep away everything on the ocean coast worldwide with a devastation more thorough than a total nuclear war.

NUCLEAR POWER TO REPLACE FOSSIL FUELS

Since we cannot imagine a dike 200 feet high worldwide to stop the encroaching ocean, we will have to stop the increase of carbon dioxide in the atmosphere before it is too late. Fossil fuels must be replaced. The only alternative is nuclear power—fission now and fusion in the future; all other energy sources—hydraulic, geothermal, wind, etc.—are of no consequence. Thus, we have to re-openthe wound of the hotly debated issue of nuclear power. it is an all-encompassing issue and once again cooperation is the guide for a successful solution.

This is no place to review the whole nuclear safety issue. But a few salient points of recent developments may illustrate the essential nature of the problem and show the way of resolution. In 1987 France reached 70% nuclear in its electric power. Several nations have over 50%. Nuclear power has become an essential element of the economy of many nations. It is here to stay, like it or not.

Although France led the pro-nuclear nations, not far away in the same European community there are countries with intense anti-nuclearsentiment, such as Austria and Sweden. Faced with such diverse and opposed opinions, it is clear that the anti-nuclear sentiment is a political choice and personal taste, having no scientific merit and historical significance, like the Prohibition Movement in the US before the 1930s.

THE DON QUIXOTE SYNDROME

Part of the nuclear fear originates from the incomprehensibleness of new, strange technology. Everybody knows the story of Don Quixote charging into the windmill. What is little noticed is that the windmill is a power plant, a new, hard technology incomprehensible to the medieval dunce, and thus appears as a Devil that invites a holy war. But now wind energy is welcomed as a benign, soft technology embraced by all environmentalists. In the future when people are busy building a 200 foot high dike, nuclear power will be regarded as benign and soft, and today's anti-nuclear activists will be looked upon as new Don Quixotes.

THE LAPLACE DICTUM

The originator of probability theory, Laplace, has commented that when the stakes are high, people will not be persuaded by the rationale of probability considerations. That is why so many people are buying lottery tickets, even though the gambling "expectation" is almost nil and no rational being guided

by probability theory would ever entertain the idea of investing in it. The same applies to high stake risks, such as a nuclear meltdown. The fear is more than justified by the calculated probabilities. However, the same safety-conscious people do not mind several hundred coal minerfatalities a year in the same way that no one buys a $1 lottery ticket that will win $1.10 no matter how high the probability of winning.

ALLEVIATE THE NUCLEAR FEAR

These psychological studies indicate that the nuclear fear can be alleviated by a proper educational program. A gambler can be rehabilitated by Gambling Anonymous. A little bit more scientific education can remove the Don-Quixote syndrome by peeling off the veil of mystery shrouding unfamiliar technology. The Russian school textbook for seventh-grade Physics contains the essential knowledge of nuclear physics and radioactivity. That is enough to provide a base for understanding nuclear power. Most Americans outside the scientifically educated do not even have that much background. This stark failure of American education contributed much to the confusion on energy issues.

LESSONS OF THREE MILE ISLAND AND CHERNOBYL

Just how high are the stakes of nuclear risk? The Three Miles Island and Chernobyl accidents have been considered as serious blows to the nuclear industry. But some see a silver lining in the dark cloud. The Three Mile Island was a serious accident but it was contained—no serious radioactive leaks and no immediate fatalities. In a sense, it is safe. Chernobyl was a full blown meltdown with substantial radioactive release. But the immediate fatalities were limited to a few fire fighters, not thousands, as is usually expected.

A close study of the two accidents may strengthen our confidence of nuclear safety. The Three Mile Island accident is exclusively due to human error, not intrinsic defects or hazards of the reactor system. If the reactor were left to automatic pilot to operate, this accident would not have happened in the first place. It was human misinterpretation of the information—a water shortage was mistaken as excess. The water supply was shut down and the reactor proceeded to partial meltdown. Error of this kind can be avoided by better control of the operating procedure.

The Chernobyl accident did not happen in the regular operation of the reactor in generating electricity, even though the instability of the graphite reactor was considered accident prone. It was a stark example of human abuse. The reactor was shut down to perform an experiment—to find out how long the turbine would continue to operate after a meltdown (what is the benefit?). To do so the reactor venue was set to simulate a meltdown. The emergency cooling system was turned off. All cadmium control rods were pulled out except 6 (normally a minimum of 30 should remain). The simulation was so realistic that it actually became real, and lo and behold, a custom-made meltdown occurred. There was no emergency cooling water. There was not enough time to insert the cadmium rods. Nothing to stop the disaster. It has nothing to do with nuclear power safety.

NEW REACTOR TECHNOLOGY

The new generation of reactors would adopt passive design: no pipes so that accidents due to pipe-breakage would not happen. No valves so that accidents due to stuck valves would not happen. The reactor would sit in a pool of water so that emergency cooling water is present all the time.

Moreover, the size of the reactor would be reduced; instead of one gigantic reactor there will be a series of small identical units. The tendency of building bigger reactors was based on economic considerations: the cost is proportional to the surface of the reactor, but the profit is proportional to the volume so that the profit to cost ratio increases with linear dimension. This earlier calculation did not include the cost of elaborate safety facilities, which increases exponentially with size. Under present safety standards, small reactors would be more economical. More important, public confidence will be enhanced. A small reactor can be perfectly contained in the event of a meltdown. It will be no more hazardous than a gasoline storage tank.

CONCLUDING REMARKS

This conference on Technology–Based Confidence–Building: Energy and Environment has been a great success and a good beginning. We agree with the recommendations suggested in the workshops during the conference.

An International Center for Research on Energy and the Environment should be established with a scope that included basic sciences, technology, development, and policy formulation.

Collaborative projects should be developed addressing end-use energy efficiency for all sectors of the economy, and all emphasis should be given to minimizing adverse environment impacts.

Calamities, natural or human-induced, catastrophic or episodic, will always be present and will proliferate as civilization advances. The involvement will become more complex and cooperation between related sciences and technologies, various segments of the society, and nations in the world community will play a more important role and will guarantee success in building a more livable world.

GLOBAL WARMING AND ENERGY USE

by

Senator Pete Domenici

Hello everyone, I am Senator Pete Domenici, and I am real sorry that I can't be with you for your conference today, but I would like to talk about the new challenges facing our global environmental problems, specifically, global warming and energy use. Let's look at what is happening on the international front. The other day I heard a private talk given by a former leader of one of the great European democracies. He talked of many things, but during his talk, he cited four overriding problems that confront mankind, problems for us, for our children, and for their children. Those concerns include population growth and the world environment, in particular, global warming. I want to spend the remainder of this time discussing those challenges, particularly, the second one.

The challenge is on our planet, on which the median temperature seems likely to be rising, quite possibly at a dangerous rate. We know that global warming, " the greenhouse effect," could be a disaster, a disaster unlike any this planet has experienced during mankind's tenure.

Many scientists predict that the accumulation of CO_2 and other gases will raise the planet's mean temperature in the next fifty to sixty years by three to four degrees Celsius, the same increase that brought us out of the "Ice Age" 18,000 years ago. This issue is so complex, scientifically, that it is not clear whether or not these forecasts are accurate. But we don't have the luxury of waiting until we know for certain what increases might occur. I think that we must recognize that a greenhouse cataclysm is possible; we must do all that we reasonably can to build a global awareness; and we must start action while more data are developed. Although global warming or the extent of warming may not yet be conclusive, one thing that is absolutely certain is that the number of people on this planet will continue to increase at a startling rate. In the year that I was born, 1932, about two billion persons lived on planet Earth. Today, there are just over five billion of us. The United States Population Fund now predicts that by the year 2025, 36 years from now, there will be between eight and a half and ten billion human beings living on this planet. As human experience tells us, each of those individuals will be seeking material advancement and a better life for themselves, certainly a better life than their parents experienced in 1989.

Our country's policy is to encourage prosperity. The hallmark of America's world leadership since World War II has been to foster democracy and economic growth. But what that means, of course, is that the world of the early 21st century will not only be far more populated, but it will certainly be a world of far greater consumption than exists today. And of that huge increase in population, about 90 percent will occur in nations of the Third World. Now these developing nations will demand, and justly demand, their fair share of economic growth. They will very possibly experience a growth rate faster than our own. So with that framework, let me pose a question; "What is the fundamental component of economic growth, the growth for which billions of humans are and will be clamoring?" The answer is energy. Without energy our standard of living will collapse, and mankind's survival will be threatened. That doesn't mean that we can't be more efficient in our use of energy, but the combination of the twin growth in population and human expectations makes it certain that energy demand will expand dramatically. And since the burning of fossil fuels is tied so very closely to what appears to be warming of the planet, we confront a situation that we dare not avoid.

We as individuals, as a government, and as government officials, face a challenge that can only be called staggering. The risk of doing nothing is horrendous. We must act, and we must begin to act

promptly to meet this challenge—not just the challenge of protecting our climate—but the challenge of ensuring that energy is available for mankind's progress and that that energy be clean. We cannot wait until incontrovertible scientific proof appears to validate or invalidate the estimates on global warming.

With all this in mind, I have concluded that we will not suddenly scale down energy use. Such a change will be politically untenable and may not even be efficient. We won't do that in the United States, and in Europe, and in the overdeveloped countries. The developing nations simply will not accept the fact that they cannot improve their standard of living because America is the richest and most powerful nation, the nation that is responsible for about 25 percent of the man-produced carbon dioxide and an almost equal amount of the goods and wealth of the world. We simply must take the lead in addressing the climate situation that will affect all human beings. Recognizing all of that means that we must take the lead to develop a comprehensive energy plan that will not endanger our atmosphere, that is, an international energy source, or perhaps create an energy bank, or perhaps proceed with something like a Marshall plan in energy. If we don't, I can assure you that no one else will.

For a million years CO_2 was in balance on the planet. Nature produced and consumed about a hundred billion tons of CO_2 a year through the natural cycle of photosynthesis and respiration. We were upsetting that balance when we began to burn wood and, later, coal and oil, in vast quantities. Even though man's activities produce just six billion tons of CO_2—about one ton per person per year—much of that six billion tons has not been consumed in the environment but is accumulating in the atmosphere. Now we cannot eliminate the buildup, but I would like to suggest several steps that I believe are a prerequisite to reducing the rate of the future carbon-dioxide accumulations. These are not magical solutions, but they will definitely move us forward.

First, President Bush is absolutely correct in calling for negotiations on an international treaty on global warming. That has been done, and the conference will take place beginning this October in Washington, DC. Forty or so nations will examine the financial, economic, technical, and legal issues responding to climate change. Once these nations develop the framework for an international treaty, they will take that document to meetings of the International Government Panel on Climate Change next summer for further evaluation. I can't begin to suggest to you what such a treaty will look like, but I am encouraged that we are moving forward.

Second, I recommend that the White House establish an inter-agency group to develop policy options on ways to reduce CO_2 emissions and submit those proposals to the Congress. It would be appropriate if such a task force were lead jointly by the EPA administrator and the Secretary of Energy of the United States. I must tell you that last fall I was able to work with Senator Leahy of Vermont to get $13 million so EPA could begin to study the implications of global warming, and that was a good start.

A related concern is research in basic science on global climatic change. Overall, believe it or not, in the current fiscal year budget, the federal government is spending $134 million for that kind of research. Next year, in the President's budget, Congress will be asked to approve $190 million. That sounds like a lot of money. I support it, but I warn you of one unfortunate fact—there really isn't much coordination in this spending, which is spread among a half dozen agencies. We must find better ways to focus that effort more efficiently and effectively to develop solutions to particular problems. And certainly, our national laboratories, including Los Alamos and Sandia and others, have the skills and knowledge to become leaders in this effort.

My third and primary proposal is this: the United States should call for and be a lead participant in an international energy conference to encourage all nations to begin to address energy use and new sources that are compatible with our world's environment, including new technologies such as clean-coal technology.

Our nation must take the lead in encouraging the use of sources of energy other than fossil fuel or to clean them up dramatically. That doesn't mean that our oil fields will be closed down. What it means is that we absolutely must increase our research into alternative, cleaner sources of energy and cleaner uses of current sources. Such a conference is valid, whatever the impact of global warming. Right now the federal government is spending just over $500 billion a year for research in high-temperature fusion. We need a much more directed effort in all of these alternative clean-energy sources; what about solar, what about clean-coal technology? And while many of you may disagree with me, I am convinced that we must move toward a greater use of nuclear energy. We must move toward a long-term world-wide energy policy, particularly one that encourages technology transfer assisting the Third World. And we certainly need to bring the industries in countries around the world into this kind of dialogue.

Before closing, let me cite the example of China. Although we know that China is having other problems, let me just talk about China and this issue. China, today, produces an estimated 10 percent of the man-made CO_2, and China, with its population exceeding one billion, is in the midst of its own industrial revolution. China also happens to possess vast quantities of coal. That resource could propel China into the First World. It is a resource that will obviously accelerate world-wide CO_2 emissions. It is also higher sulfur coal, the kind that produces acid rain. Do we tell China you can't use your coal, and even if we did, would they listen. I think the answer is obvious. It will only be through a coordinated international effort that countries such as China will be able to leap into the future without committing horrendous damage to this planet. And they will do that only if the industrial nations decide in a concerted way to help push and transfer technology for cleanup.

Mankind has probably never faced a more difficult challenge. It is one that will require a great deal, both scientifically and politically, even if the problem is only a fraction as bad as some forecast. Most of you know that I am an optimist, and I believe that we can meet that challenge. But we will only meet it if we recognize it for what it is—possibly the greatest challenge in the history of this beautiful planet. I want to thank you for what you are doing at your conference, and I hope you have a very successful meeting.

AGRICULTURE: AN AREA RIPE FOR COOPERATION

by

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In 1989, the world food picture is not a pretty one. After several years in which a "grain glut" dominated that picture, the unexpected and unprecedentedly severe drought of 1988 in North America and northern Eurasia caused the global grain harvest to plummet for the second consecutive year. The 1988 harvest was some 10 percent below that of 1986 (and the world population was 3.5 percent larger). The sudden drop in production reduced world carry-over supplies to the "pipeline" supply, leaving no margin for a shortfall in 1989.

The 1988 drought afflicted the prime grain-growing regions of North America, China, and the Soviet Union. Whether the drought was a manifestation of greenhouse warming, we probably will never know, but it was the kind of event that climatologists predict to become more frequent as human-generated greenhouse gases continue to build up in the atmosphere.[1]

That a dependable food supply system is an essential element in international security is not doubted by anyone who has given the matter thought. The global changes in climate that are likely to result from the buildup of greenhouse gases in the atmosphere pose a great threat to the stability of the world agricultural system, though they are largely unpredictable in detail. These matters, however, are being addressed by the world scientific community, and the world's political leaders have begun to grapple with them as well.

But it is less widely appreciated that, even apart from such unpredictable dangers, civilization's modern agricultural enterprise is in many ways unsustainable in the long term. Symptoms of this unsustainability are the unacceptably high rates of soil erosion, overdrafts of aquifers, and damage to irrigated farmlands seen around the world.[2] Food production must continue expanding for the foreseeable future to meet the needs of the growing human population, yet keeping food production ahead of population growth is becoming more and more difficult.

Nowhere are the problems of increasing food production more dramatically highlighted than in the Soviet Union. A recent report by the Associated Press quoted a senior Soviet minister to the effect that, unless Soviet agriculture was reformed, the nation was facing famine.[3]

That agricultural production in the Soviet Union has lagged in recent decades is no secret to anyone who has paid attention to global food production trends. Ever since the great grain purchase of U.S. grain by the Soviets in 1972, which caused grain prices on the world market to skyrocket, the Soviets have been dependent in most years on significant imports to meet domestic demand for grain and meat. In 1989, following a grain harvest reduced by the same drought conditions that sharply reduced the 1988 harvests in North America and China, the Soviets are expected to import some 45-50 million metric tons of grain.[4]

But Soviet failure to meet its planned grain production is nothing new. Since the record Soviet grain harvest in 1978 of 237 million metric tons (mmt), production did not return above 200 mmt until 1986 and has yet to approach the 1978 record again, although targets have been set each year of over 230 mmt. Throughout the 1980s, the USSR has been a steady grain importer on the order of 30 mmt per year.

The reasons for these chronic problems are several. One is that much of the Soviet grain belt is far enough north that early and late frosts frequently damage tender shoots or ripe grain waiting to be harvested. This problem, however, is compounded by the inefficiency of Soviet farms, which often are operated as though they were factories. Visitors to Soviet farms have reported that at five o'clock a whistle blows and the harvesters quit and go home, regardless of whether the crop is in and a storm is predicted. This is in stark contrast to an American farmer, who will keep working until the crop is in, at least while daylight lasts and often into the night if bad weather threatens. A similar lack of urgency occurs at planting time, which can easily delay maturation of crops until early fall, when frosts are likely.

Inefficiency is also a result of the forced collectivization of farms under Stalin, including the displacement and deaths of millions of kulaks in the 1930s. More recently, movement to the cities by young people has left the farms in the hands of less skilled and elderly people, further lowering the quality of farm workers.[5]

The Chinese recognized over a decade ago that collective farming offers little incentive for efficient and productive farming. But the Chinese are a generation less far removed than the Soviets from traditional farming practice; nor had they lost millions of experienced farmers. Restoring an entrepreneurial spirit to farming will be much more difficult for the Soviets. Even so, limited experimentation in the early 1980s with tiny private plots (less than a half hectare each and totalling only 1.3 percent of the nation's farmland) resulted by 1982 in those plots producing 15 to 20 percent of the Soviet Union's food. Of this, two-thirds of the potatoes and eggs and one-third of the meat and vegetables on Soviet markets came from private farm plots.[6] Despite this early success, expansion of the program appears to have been slow and cautious.

Also unlike the Chinese, the Soviets have clung to their centralized system of agricultural management. Such a system can never be as efficient as on-the-spot decision-making by farmers in the context of local weather, crop conditions, and needs for inputs (fertilizers, pesticides, etc.). The Chinese unleashed this capacity by relaxing the centralized control of farmers, whereas the Soviets are only beginning to do so.[7] Chinese grain production, which had closely paced that of the Soviets for several decades, surged ahead in the early 1980s while Soviet production slid downward.[8]

Nevertheless, following the 1985 reorganization of the agricultural administration, some improvement in grain production has been seen, along with moderate rises in meat production. Centralized control of farm wages and food prices has been relaxed somewhat, although substantial increases in productivity have not yet materialized.[9] Judging from comments reported in the press by Soviet citizens and from observations of food available in markets there, progress has been disappointing.

Besides its serious operational inefficiencies, Soviet agriculture suffers from effects of various severe environmental problems, including air pollution, acid precipitation, water pollution, and soil erosion. Details of these problems were not widely available until recently. With the coming of glasnost and revelations of widespread environmental problems, this has changed dramatically. Many severe environmental problems either have their sources in mismanaged agricultural systems or have caused damage to agriculture, or both.

Fyodor Morgun, the first chairman of the new State Committee for Environmental Protection of Nature, vividly described some of the worst problems in an address to the 19th Party Conference in June 1988:[10] "Water quality is deteriorating nearly everywhere.... Unless serious measures are taken immediately, water in some parts of the basins of these rivers will very soon be unfit to drink and use for irrigation.... The Aral Sea is an ecological disaster area....

"Rather than being applied properly to our soil, chemical fertilizers are being thrown around. But in Nature nothing is lost. They run off into reservoirs and then turn up in the waters of the Volga, Dnepr,

Don and other rivers in the form of blue-green algae and other pollutants that are harmful to every living thing...."

Much of the recent testimony on Soviet environmental problems reads uncannily like exposés in the United States and Western Europe in the late 1960s and 1970s. Indeed, such stories still appear regularly in Western newspapers, journals, and on television. The scandal in the United States over residues of the pesticide Alar in apples and apple juice (fed in large amounts to vulnerable infants) is a recent case in point.[11]

But environmental problems in the Soviet Union, especially those related to agriculture, appear to have developed further, out of the public eye. A Swedish professor, Stefan Hedlund, reporting on problems in Central Asia, declared that destruction of the region's environment had "progressed beyond the point of recovery."[12] He and others have described the Aral Sea's troubles: its surface has been reduced by a third and its volume by two-thirds, as water for irrigation has been taken from the rivers that feed it. The sea's shores have receded by some 80 kilometers, stranding towns. Important fisheries have been ruined by rising salt concentrations in the sea. As the Aral Sea has shrunk, the climate has shifted to hotter and drier summers, colder winters, and shorter growing seasons. Once a major source of cotton, rice, fruits, and vegetables, the area's future for agricultural production is very much in question.[13]

The sea's surroundings are fast being turned into a salt desert as the wind disperses tons of salt from the dying sea over the once-productive farming area. Hedlund quotes a Soviet academician who traveled across 300 kilometers of "what appeared to be a snow-covered plain stretching to the horizon without a sign of life."[14] The academician expected the same fate to befall the Caspian Sea and its surrounding regions.

The chairman of a public committee investigating the Aral Sea situation recently found evidence that the original designers of the region's irrigation system had planned to grow rice on the dried-up seabed as the sea was drained.[15] But they apparently did not reckon on salt build-ups. Now, each year, wind and rain carry millions of tons of salty dust and sand as far as 1000 kilometers from the seabed. Finer salt and dust, along with chemicals and pesticide residues, have been carried up to 5000 kilometers, increasing the saltiness of rain in places as distant as Byelorussia and Lithuania and accelerating the melting of glaciers in the Altay and Panier Tienshan mountains. The effects of a fine deposit of salt on the fertility of thousands of square kilometers of farmland can be imagined.

The pesticide deposits are blamed for serious health problems throughout the area surrounding the Aral Sea; they also quite likely are causing significant problems in the region's ecosystems and farms. Pesticide problems are apparently widespread; near the border with Rumania, fruits, vegetables, and wine poisoned with pesticides have caused significant health problems. Excessive use of pesticides on rice fields and rising cancer rates in the region north of the Black Sea prompted a resident to write to the editor of Novy Mir: "We feel that chemical warfare has been declared against us."[16]

Soil erosion has plagued Soviet agriculture since long before the revolution, resulting from repeated attempts to farm the fragile central Asian steppes. Attempts in the 1950s to open new farmlands in the semi arid steppes—the so-called Virgin Lands project—proved largely disastrous, and much of that land has since gone out of production.[17] According to Hedlund, even the once rich "black earth" region north of the Black Sea, which includes some two-thirds of the nation's arable land, has lost 25 to 40 percent of its topsoil in the last decade.[18]

Since 1977, about 13 percent of the Soviet Union's total grain area has been abandoned—roughly one million hectares per year. That much of the remaining land has also lost fertility is suggested by the lack of improvement in production despite huge increases in fertilizer applications.

It may not comfort the Soviets to know that similar problems exist all over the world. Americans might easily have repeated the Aral Sea story if an inland sea existed in the midst of our arid West. Instead, we have exploited an underground sea, the huge Ogallala aquifer underlying the Great Plains. No fisheries have been lost, but the water is being pumped out to support our grain production at rates dozens to hundreds of times the rates of natural recharge. Some cropland in the southern Great Plains has already been taken out of production as pumping has become uneconomic. More will certainly follow in the next few decades.[19]

Americans too have their salt deserts created by poorly managed irrigation schemes; the Imperial Valley in southern California is suffering from salt build-ups, and the San Joaquin Valley is not far behind. Large areas of the U.S. Southwest have been desertified through overgrazing and overcultivation. Indeed, these problems are to be found in almost all arid or semiarid regions of the world from Australia to the Sahel.

Soil erosion also is not an exclusively Soviet problem,[20] although the consequences seem to have reached more severe levels than in many other nations. The United States is far from immune, although a recent change in policy is expected to bring a substantial reduction in the rate of soil loss, which around 1980 was an unacceptable 4 billion tons per year. Declines in productivity, despite the masking effect of higher applications of fertilizers, have been detected in some of the richest American farmland.

Besides these normal hazards of intensive modern farming, Soviet agriculture has also suffered from two unprecedented accidents: that at the Chernobyl nuclear power plant in 1986 and the mysterious nuclear accident in the Urals that occurred in 1957. Little is yet known about the latter event (the Soviets only recently disclosed its occurrence publicly), although 10,000 residents were evacuated at the time, and an area of 375 square miles reportedly was contaminated with radioactivity.[21] The extent of damage to agriculture from Chernobyl is still being assessed, although a great deal of the region's locally grown food had to be destroyed in the wake of the accident, and large amounts of land were subsequently taken out of production because of high levels of radioactivity.

If the United States has a parallel, other than Three Mile Island (which fortunately produced trivial effects), it is the recently revealed local pollution produced by nuclear-weapons-making facilities at several sites around the nation. Deliberate pollution of soil and inadvertent pollution of underlying aquifers with radioactive materials, highly toxic chemicals, and often a mixture of both, have occurred.[22] Both the effects on farm products and on the health of people living nearby have yet to be assessed. The former is probably not extensive, given the relative isolation of many of the facilities, but the health effects may well prove to be significant for many thousands of people. And it appears that these problems, too, are shared by the Soviet Union.[23]

Underlying all the modern environmental and social problems of Soviet agriculture is a long-standing scientific one, which ironically highlights the dangers of mixing science with ideology. In the 1920s and 1930s, Soviet science included a number of world-respected evolutionists and geneticists.[24] One geneticist, T.D. Lysenko, however, subscribed to a theory of evolution based on the inheritance of acquired characteristics, an idea originally proposed by Lamarck in the early nineteenth century. Interestingly, Lysenko seems to have made a positive contribution to Soviet (and American) agriculture by developing winter wheat.[25] But in other respects, he was a disaster.

Somehow, Lysenko gained political power, blending his ideas on inheritance with communist dogma, and managed to have suppressed Soviet biologists who propounded Darwinian evolution and Mendelian genetics. Many scientists left the country; others unfortunately perished or were banished to gulags by Stalin during the 1930s. Soviet agricultural science has never recovered from the disappearance for practical purposes of the sciences of evolutionary biology and population genetics from the scene. Among

subdisciplines that seem never to have gotten off the ground in the Soviet Union, partly as a result of the purges, is ecology—and the insights to the workings of agricultural systems that its study can provide.[26]

In the United States, the intellectual equivalent of Lysenkoism—creationism—has substantially inhibited the teaching of evolution in secondary schools, to the great detriment of public understanding of such problems as pest resistance to pesticides, resistance of pathogens to antibiotics, and the importance of preserving genetic diversity, both in domesticated plants and animals and in natural ecosystems. Moreover, U.S. agricultural science has been for too long isolated from academic evolutionary biology and ecology (and some of our more unfortunate agricultural policies have resulted),[27] but by no means to the degree that it apparently has in the Soviet Union. Modern genetics has been an integral part of agricultural modernization in the United States (and other Western nations) at least since the 1930s, when hybrid corn was first developed.

I do not mean to imply that agricultural science has totally stagnated in the last 50 years in the Soviet Union, but it clearly has not "progressed" as Western agriculture has. Perhaps it would be fair to say that agricultural research and development in both nations today would benefit from a renewed infusion of modern evolutionary theory, along with a judicious application of biochemical genetic engineering.

The Soviets do not seem to have an "organic farming" movement equivalent to that in the United States (and to a degree in the United Kingdom and Europe), which is now belatedly gaining respectability with the US agricultural establishment.[28] "Organic farming" in essence is based on little or no use of artificial inputs (fertilizers and pesticides) and careful husbandry of soil. A related scientifically-basedapproach to reducing the environmental effects of using pesticides is "integrated pest management" (IPM), a regime that relies primarily on biological and cultural methods to control pests and resorts to chemical poisons only when absolutely necessary.

The experiences of the organic farming movement, the IPM practitioners, and a handful of agroecologists doing research mainly oriented to tropical situations, could be of immense value to the Soviet Union's troubled agriculture. It is worth noting here that the Chinese also have profited from essentially ecological experimentation in their agricultural system; when China opened to the West, Chinese agricultural researchers were reportedly amazed to find that they were well ahead of Americans in this kind of research. Both the US and USSR could learn from their experiences.

Much has been said and written (and initiated) about cooperation in addressing environmental problems common to both nations as well as joint action on global environmental problems, such as depletion of the stratospheric ozone layer and the greenhouse warming. With respect to the latter, I will simply note that they (and efforts to address them) have very important implications for agriculture and food production.[29]

Environmental problems connected directly to agriculture—soil erosion, pesticide and fertilizer pollution, mismanaged irrigation systems and their consequences—also have their counterparts in the West. In these areas, the Soviets have some lessons to pass on to us. Unfortunately, some of the lessons can serve as horrible examples. As Chernobyl brought home to the world, the dangers of nuclear power, the misfortunes of the Aral Sea and surroundings can tell us what diverting too much water from an ecosystem (as has been attempted with the Colorado River system, for example) can accomplish. The disasters in the Soviet Union are not unique; in many cases, they are the result of doing the same things that Americans and Europeans are doing, but more enthusiastically and carelessly—overusing pesticides and chemical fertilizers, for instance, and failing to protect against soil erosion.

Boosting grain production in the short term has been a watchword for both the East and the West in recent decades. The United States has only recently made some changes in policies to prevent further

deterioration of its key agricultural resource—soil. Much more is needed, and perhaps the lessons of Soviet agriculture may spur us to make the additional required changes, while we offer to help the Soviets in moving in the same direction.

An exchange of information, research techniques and findings, and ideas at all levels from the most practical experiments in farm fields to the laboratories of biological theoreticians might prove enormously helpful to both societies. Similarly, a joint program between the United States and the Soviet Union for students to take degrees or do post-doctoral study in the other nation could facilitate the exchange of ideas and techniques. Such programs could usefully be initiated or expanded in several subdisciplines of biology (from ecology and environmental sciences to genetic engineering) as well as in applied sciences such as agriculture, integrated pest management, conservation biology, and restoration ecology.

The world's food situation is none too secure today; humanity cannot afford to jeopardize the future productivity of any major agricultural region, be it North America or northern Eurasia. The threats to agriculture, furthermore, of global environmental problems such as the greenhouse warming and increased UV-B radiation, make it all the more urgent to find solutions to these problems, preferably in cooperation. Indeed, it is hard to see how it could be successfully accomplished otherwise.

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WORLD-WIDE SOLAR-POWER SATELLITE SYSTEM (WWSPSS) TO REDUCE CO_2: DO YOU HAVE A BETTER WAY?

by

Melvin Eisenstadt and Jay Sorenson

PART I - TECHNICAL, FINANCIAL AND ENVIRONMENTAL ASPECTS

Back in the late sixties, Glaser[1] proposed a method for generating electric power in space for use on the earth. Reactions to the proposal ranged from enthusiasm to mild cynicism. The basic concept is straightforward. Large arrays of photovoltaic (PV) cells would be placed in geosynchronous orbit about the earth, and the power that they generate would be sent to earth by microwave transmitters, to be received by microwave receivers and put into the distribution grids. It has since been suggested that the microwaves can be replaced by lasers.[2] New situations, political and environmental, have arisen that make the Solar Power Satellite (SPS) highly attractive, those being the recent softening of US-Russian tensions regarding disarmament and the growing concern about the greenhouse effect. Although this may provoke the cynics, we will take this concept and explore how it can replace fossil-fuelpower plants and gasoline world-wide, reduce international tensions, cause very significant reductions in carbon dioxide emissions and we will even point to a source of funding large enough to make such a massive venture feasible.

TECHNICAL CONSIDERATIONS

A. The SPS

A good deal of analysis has been done on the SPS by better analysts than we claim to be (2,3,4), and no new technical analysis is presented here. Some parameters of importance later in the paper are introduced. Most of the data presented in this section come from Reference 4. A number of different systems were considered there, including GaAs solar cells, multi-bandwith solar cells, etc. The report finally settled upon a "reference satellite," understanding that it will probably change as solar-cell and other involved technologies advance. The reference satellite and supporting equipment delivers 5 Gw to the utility grid. It is indeed a massive thing, measuring 16 000 meters in length by 4 200 meters wide, and having an area of about 70 square kilometers. The necessary power transmitting-equipment adds to the size. The antenna has a diameter of 1 km. The receiver for the 5-Gw reference satellite is an ellipse, 13 km by 10 km, with a power intensity of 23 mW/cm^2 at the center and 0.1 mW/cm^2 at the periphery.

B. How Many Satellites Are Needed?

The most logical carbon-dioxide producer for the satellite to replace is the thermal-electric power plant. In 1986, the world had an electric generating capacity of 2 460 436 Mw, of which 1 614 128 Mw was in thermal plants.[5] The United States had 34% of the total, or 547 111 Mw. Part of this is for baseload, and the remainder is made up of intermediate and peaking units. It is assumed that the SPS will be used for baseload only. It is further assumed that 60% of this thermal capacity services baseload and that the

SPS will replace baseload capacity only. Thus, about 968,477 Mw are out there that can be replaced. The reader may wish to quibble with the assumptions. Keep in mind that the reason for this exercise is to try to get some idea of how much it will cost to replace terrestrial power plants and run most of the world's transportation sector on electricity rather than gasoline.

During 1986, 1 614 128 x 10^3 metric tons of motor gasoline were consumed in the world, 42% of which was consumed by the United States (Reference 5, pg 90). Using a heating value of 19,100 Btu/lb for gasoline, this comes out to be 19.93×10^{12} kwh. Assuming that an SPS produces 100% of rated capacity for 90% of the time (or vice versa), the generating capacity required to produce the 19.93×10^{12} kwh turns out to be 2 280 Gw. It is now assumed that the efficiency of an electric automobile is about three times that of an internal combustion engine, resulting in a generating capacity of 760 Gw to replace gasoline. We were unable to find figures for diesel consumption, and it is assumed that aircraft and ships will continue to use fossil fuels. Thus, the SPS generating capacity needed to replace baseload power plants and motor gasoline is 1 728 Gw or 345 reference satellites of 5 Gw each. This is indeed a massive undertaking, requiring 26 460 square kilometers of solar cells and a land area of about 38 575 square kilometers for receiving stations. The number of reference satellites needed to replace US fossil fuel plants is 66, using the above calculating method. Glaser estimates that 60 are needed[6,pg.280], showing very good agreement.

COST AND COST JUSTIFICATION

A. How Much Does It Cost?

Reference 4 does some economic analysis and concludes that the systems considered will cost between $2 310 and $3 670 per Kw, based on 1979 dollars, with the reference satellite costing $2 959/Kw. This paper will use the higher value. The Consumer Price Index rose 77.3% between January of 1979 and January of 1989; therefore, the present cost per kw would be $6 507/kw, assuming that the CPI is an appropriate index for SPS purposes. It is interesting to note that the cost of power delivered to the grid, not from the grid to the customer, is 4.1 cents per kwh in 1979 dollars, or 7.27 cents per kwh after adjustment by the CPI, based on a cost of money of 9.84%, 90% system availability and a 30-year lifetime. Although this is very high, it is not out of sight.

The cost of the SPS can be found by merely multiplying the cost, $6 507/kw, by the generating capacity needed, 1 890 Gw, and we find that only $11.244 trillion are needed. It should be noted that the consumption figures used in arriving at the cost are for 1986 and no adjustment for growth is included.

B. Justification and Time Frame

A cost of $11 or $12 trillion is staggering. It does not take an economist to understand that this could have a significant effect on the amount of capital available world-wide for new ventures and economic growth. Funding would probably have to come from national governments since it is doubtful that such sums are available from traditional capital sources. To justify the expenditure, it must be shown that there is a reasonable return on the investment.

The return on investment rests upon the assumption that the greenhouse effect is real. We understand that its reality is controversial and the controversy is generated in part by the admitted inability of the

meteorologists to model the oceans accurately.[7] There seems to be no disagreement about the fact that the carbon-dioxide content of the atmosphere has been increasing since the industrial revolution. Estimates show that the Antarctic ice cap could melt within about 100 years and the oceans would rise about 2 or 3 meters.[8] This could cause the largest disruption to coastal areas since Noah set sail in his Ark. What is presently known as South Florida could become a coral reef. Bangladesh might go under water; Venice and Leningrad could disappear; Indonesia, with the fifth largest population in the world, would be severely impacted; etc. The expenditure could probably be justified by the loss of real property in coastal cities, unless there is a cheaper way to solve greenhouse-effect problems. Perhaps the world would have a system of dikes like Holland, but what is the cost? In addition, there are the economic, political, and social consequences of unknown weather changes, such as the cost and tensions of relocating people from low-elevation coastal areas, world-wide. The SPS would also buy us a clean atmosphere. The value of the real property lost can be calculated. Thus, an investment of $11 trillion is needed over a time frame of thirty to fifty years, or about $300 billion a year is needed.

C. Who Pays?

The greenhouse effect was caused by the developed nations burning fossil fuel as a cheap energy source, and it is cheap energy that fueled the Industrial Revolution. The developing nations did not create the problem and, justifiably, should not be billed for the solution. They would probably not be inclined to cooperate since higher energy rates would slow their rate of development and they would not be inclined to contribute resources to clean an atmosphere fouled by their more affluent neighbors. Thus, it would appear that the developed nations would have to pay for the satellites and should sell power to developing nations at rates comparable to those of fossil-fuel power plants, at least for some finite length of time. The time could be pegged to the extent of industrial development or some other parameter that ensures that the presently developed countries are not at a world trade disadvantage when additional countries reach an industrially developed condition.

INTERNATIONAL MONEY SOURCES

At present, East-West tensions show signs of diminishing as a result of apparent US-Soviet willingness to participate in meaningful arms reduction. Simultaneously, the world is faced with impending environmental disaster as a result of the greenhouse effect, or at least major disruption, albeit 50 to 100 years down the road. World cooperation is needed to resolve the problem of global warming, and the United Nations is initiating meetings on this topic.[9] Growing vulnerability to environmental insults, ecological interdependence, and the need to cooperate on a world problem should further reduce tensions. One result of reduced international and regional tensions would be smaller defense budgets, and the reduction in those budgets could be used to finance the SPS. More importantly, the logic could be reversed. If we do not solve the problem, we will have to live with the course Nature is taking. To allay global warming and its consequences, the developed nations of the world will have to come up with $300 billion a year. While the carrot approach is a nicer one, the stick can be equally effective. The money can be taken from the defense sector with less upheaval to the world economy than from any other source we can think of. The world's scientists who are currently engaged in weapons development and defense could utilize their talents for SPS, and a change from defense to SPS could be managed incrementally so it would be least disruptive to the technical community.

For purposes of comparison, the US government has a budget of $1.3 trillion for fiscal year 1989, of which $300 billion is for defense.

ENVIRONMENT, SAFETY, AND HEALTH CONSIDERATIONS

As in the previous section on technical considerations, much of this section on environment, safety, and health (ES&H) comes from Glaser's work[6] for the SPS concept. Although the SPS compares favorably with the more serious impacts of fossil-fuel and nuclear-energy conversions systems, Glaser notes: "it would result in environmental effects that could be quantified only after additional research [is] performed."[6,pg.279]

This statement means that the ES&H impact of the SPS is largely unknown. Little data exist, and there is no consensus on critical international standards for ES&H protection. As is the case for all other energy sources, ES&H values will drive SPS technology, although SPS is entitled to large credit for reducing the negative effects of burning fossil fuel. Even as an unknown, they serve as a major constraint on the development of SPS. Although SPS will help to overcome serious environmental problems, such as the gradual warming of the earth, ES&H considerations should not be treated as secondary problems to be retrofitted onto SPS technology. This is the mistake the nuclear-energy industry made in the US

The major environmental issues identified in the SPS Concept Development and Evaluation Program (CDEP) are[6]:

- microwave exposure on health and ecosystems;
- nonmicrowave exposures on health and ecosystems;
- effects on the atmosphere;
- electromagnetic compatibility; and
- laser system effects.

We have added two more to the original CDEP list:

- effects on wildlife habitat and wildlife; and
- effects on unique natural areas and genetic diversity.

A quick look at direct and indirect environmental effects indicates that these may not be as formidable as cost constraints, but some demanding problems remain and require further research. Among the more prominent unknowns are:

A. Microwave Radiation on Humans

International standards on safe human exposure levels have not yet been set, and scientific opinion on the range of safe exposure levels reflects the absence of a consensus, ranging over four orders of magnitude in difference[6,pg. 280]

To make matters worse, different nations are applying different criteria and have adopted different standards. The US and Western Europe have adopted 10 mw/cm^2 as a guide for continuous individual and occupational exposure. In contrast, Canada has a lower standard of 1 mW/cm^2. The Soviet Union and Eastern European countries have an even more conservative standard, allowing only 0.001 mW/cm^2 for long-term public exposure. They allow an occupational exposure of an order of magnitude higher.

The different standards and the profound controversy about the health standards of low-intensity microwave exposures (including skepticism about the validity of the observations) will affect and delay any decision on acceptable technologies. A better theoretical understanding and quantitative assessment of the biological implications of SPS microwave power transmission is essential if microwaves are used. So, too, is an assessment of its effects piled on top of an increasing number of industrial, medical, and domestic sources. No headway can be made unless the microwave standards are acceptable to all nations in the international community. We suggest that one way to solve the consensus problem is to temporarily accept the most conservative public and occupational standards—viz, those of the Soviet Union and Eastern Europe. These are problems that would be worthwhile dealing with in this early stage of SPS concept exploration.

B. Occupational Exposures

Occupational exposures to the SPS microwave power densities must be controlled both in space and on Earth. Glaser estimates the space exposures to be about 2200 mW/cm^2 and 23 mW/cm^2 for the maximum on Earth.

C. Microwave Radiation Effects on the Ecological System

No definitive data exist to assess effects of microwave radiation on ecological systems. Hence, it is not possible to confidently assess whether SPS microwave radiation would be harmful to the environment. Glaser notes that whereas controlled laboratory experiment information is available for the effects on specific animals or plant species, the data are insufficient for an informed judgement on environmental effects in general.

Honeybees have been studied and considerable data now exist on free-flying birds since they couldantenna. Although direct exposure will kill most, for those exposed to low levels for a long period of time, the relative exposures reported do not change behavior characteristics or affect survival. Extensive research is required for greater understanding and confidence in standards governing microwave exposures for animals and ecosystems.

International standards here, too, will drive the design of an SPS transmission system. Public acceptability will be as important a factor as scientific acceptability.

D. Other Environmental Effects

Because of the magnitude of the project, the environmental effects would be similar to those that any major manufacturing operation would cause. These can be evaluated by existing methods. A major difference will be space launches and space transportation vehicles for deployment and maintenance of the space power satellite in geosynchronous orbit. Some unique environmental concerns that relate to impacts are:

1) Siting. The critical siting problem is that of suitable locations. Launch and receiver facilities require exclusive user of land-raising problems of size, intensity of use, and suitable locations. The siting areas for receiving antennas, although relatively small, will be hazardous to human, animal, and plant life. Influential factors will be a need to avoid migratory bird fly-ways, unique natural areas, and areas with endangered species. The siting problem poses an environmental dilemma. Political pressures will exist to locate antennas away from population centers. However, areas not densely

populated are usually areas where most wildlife live, forests, wilderness and unique natural zones exist, and where most species diversity can be found. Environmental damage to these sites will be unavoidable and irreversible for the life of the project. Other energy sources—fossil fuels, nuclear, bio-mass, and hydroelectric—also produce similar adverse effects on forests, wildlife, rivers and wild and unspoiled areas.

2) Atmosphere and Climatic Effects. The earth's atmosphere, from the ground to space, would be affected by the construction, launches, and operation of the SPS. The extent is presently undetermined. Waste heat released at the receiving antenna's site would be small and comparable to the heat release in suburban areas. Microwave absorption in the troposphere will increase during heavy rain storms, but it is believed it will produce only a marginal effect on local conditions. However, it will be an effect in addition to existing exposures. The most important adverse atmospheric effect is expected to be inadvertent weather modifications and air quality degradation.[6,pg. 282] Launch vehicles, the frequency of space shuttle launches, and heavy lift vehicles will cause these changes. The heavy launch vehicles in particular will inject large amounts of thermal energy into the atmosphere during a launch; it may affect convection patterns and alter cloud populations as well as form ground clouds to induce precipitation. Acidity, nitrogen-oxide releases, and ozone layer effects are expected to be minimal.

As Glaser notes, weather modifications will depend largely on the type of launch vehicle, the launch location, and on meteorological conditions.[6,pg. 282] The information essential to determine mitigating measures still does not exist.

Except for microwave heating, these are typical effects associated with all space systems and missions. Laser propulsion and electromagnetic launchers are reported as possible alternatives to present fuels and chemical propulsion; the selection of vehicle trajectories and appropriate orbit insertion techniques may also minimize effects in critical atmospheric regions.

PART II - INTERNATIONAL ASPECTS

SPS PROPERTY RIGHTS

Implementing the concepts proposed in this paper will depend heavily upon the ability of the nations and corporations of the world to enter into appropriate agreements for the management of a world-wide SPS and to agree upon an equity formula regarding costs. This problem is probably as large or larger than the problems of technology and system cost. The management problems are those normal to any project of this magnitude based on a new technology. They are exacerbated by the need for international cooperation in an area that is critical to national sovereignty, i.e., control of one's energy sources.

In addition, the equity problem must be resolved. As we have proposed, the developed nations would foot the bill for the system, and SPS would sell power to the Third World at a rate comparable to fossil-fuel power plants. This obviously places the Third World in a poor position regarding control of their energy supply unless they are included, in a meaningful manner, in all decisions regarding SPS.

Finally, there are the nations that belong to neither the developed nations nor the Third World—the "in betweens." Perhaps countries like Greece and Portugal fall into this category. Criteria will have to be

agreed upon to determine who pays how much for SPS generating capacity, and this cannot be limited to categorizing the nations of the world as either developed or Third World. Should the criteria be GNP, per capita income, physical quality of life index (PQLI), contribution by a nation to the CO problem, or what?

Contrasted to the problems are the benefits of relief from the greenhouse effect problems of flooding and weather changes, as well as the advantages of a more stable world with smaller armies. Although the international problems are great, the benefits are even greater and could stimulate the required cooperation.

A. SPS Ownership

SPS will be governed in part by the 1967 Outer Space Treaty, [10] which declares that outer space, including the moon and other celestial bodies, is not subject to national appropriation by claims of sovereignty, either by means of use or occupation or any other means. The UN Committee on the Peaceful Uses of Outer Space had defined space as a global commons and part of the common heritage of mankind and has labored to implement these ideas. However, subsequent efforts such as the 1979 UN Draft Treaty Relating to the Moon [11] and the 1982 Unispace Conference [12] failed to achieve agreement on rules and coordination for outer space. Furthermore, SPS, which would probably not constitute owning a part of space, poses a dilemma and many unanswered questions.

B. The SPS Dilemma

The dilemma stems from the need for international cooperation, financing, and control of a resource, electric power, critical to all nations in an age of national sovereignty. SPS is too expensive and too important to be owned and managed by any one country, or a set of them, or by the private sector. Hence, some form of international ownership and independence is essential. Yet SPS will be so vital to the nations of the world that its organization will have to recognize the principle of national sovereignty, as was done in the Law of the Sea (discussed later in this paper). Any international arrangement will have to reflect the problem of managing the international commons by means of an organization that is built around sovereign nations but lacks an international power to adjudicate conflict between sovereign nations on issues of space. Perhaps SPS will force the formation of that international power. New tenets of international law may be needed.

At the same time, the SPS project will have to reflect the power and interests of private enterprise and public organizations in the international system. Many of the international oil companies, such as the Seven Sisters, and other affected business organizations now have budgets larger than the GNP of all but 10 to 15 nations. These international corporations probably wield enough influence to exert a veto power over any international ownership arrangement inimical to their interests and survival. They will be joined by nations whose economies depend upon the export of energy. The challenge will be to construct an international organization that recognizes the common good attainable by SPS yet accommodates the legitimate concerns of nations and organizations that would be damaged by the concept, at an affordable price.

C. The Geosynchronous-Orbit Conflict

The remainder of this section will focus on examples of the types of problems that the world-wide SPS might encounter. A systematic analysis of historical experience is beyond the scope of this paper. The conflict over the use and ownership of the geosynchronous orbit is indicative of predictable conflicts that

may arise. The conflict was and is between the nations that have the capacity to put satellites into orbit and those that do not.

The first effort to create a national property right in space was the 1976 Bogota Declaration.[13] Signed by seven equatorial countries, they declared the orbits above them to be extensions of their territorial space, contrary to the UN point of view discussed above. The Bogota Declaration has been challenged by some nations on grounds that national property rights contradict the "non-appropriation" principle of the Outer Space Treaty. Again, using the property-rights concepts, another group of developing countries proposed a licensing system for the use of geosynchronous orbits. Nations would be awarded slots, which then could be sold, rented, or reserved for future use. Another proposal for owning, managing, and capturing rental values calls for an international body to own and license the slots to bidders at an auction. This idea is analogous to the Seabed Authority in the Law of the Sea Convention, which is discussed later in this paper. Although it is understandable that nations without the ability to orbit satellites would try to get some advantage from the use of space by those who can, perhaps the world-wide SPS concept would provide sufficient benefits to all so that barriers such as those erected by the 1976 Bogota Declaration will be voluntarily lowered.

HISTORICAL MODELS

The need for international cooperation is not new and some previous experience may cast light on problems similar to SPS and their resolution. One of the success stories is Comsat—a communications satellite owned by more than 100 nations, but that arrangement does not meet the needs of a system that all nations will be dependant upon for energy. Several examples that might provide useful insights are given below.

THE 1982 LAW OF THE SEA[14]

This represents the most ambitious and advanced international convention for the management of an international commons, the oceans. It is already so widely accepted that it is becoming a part of customary international law.

The Convention on the Law of the Sea created an integrated management regime and also recognized the rights of sovereign nations over coastal waters. The Convention attempted to reconcile widely divergent interests of nations with respect to each other and vis a vis the private sector; it strove to redefine the rights of nations and to find a new basis for equity decisions in the use of the oceans and their resources. The Convention defines the common areas beyond the limits of national jurisdiction as international. It defines the sea-bed as the "common heritage of mankind," a concept called by many a milestone in the realm of international cooperation. It recognizes the legal power and self-interests of governments to apply soundobligation to do so. Under the Convention, coastal states may adopt laws and regulations for their Exclusive Economic Zones compatible with international rules and standards.

The creation of the integrated management, the International Seabed Authority, reflected an effort to reconcile two competing positions on the power of the international authority and the role of the private sector. Advanced Western countries wanted the Authority's powers limited to licensing private, public, or joint venture enterprises. They argued that a free enterprise system for open exploitation would maximize economic return to the whole world. In contrast, Third World nations wanted a strong authority, composed

of all nations, to govern the exploration, extraction, and marketing of seabed minerals and to determine how the proceeds were to be distributed.

A compromise was struck. Under the Treaty provisions, a common heritage is recognized that calls for nations to share in the proceeds of seabed mining, whether or not they extract any minerals. The integrated authority would allow national mining enterprises, including private corporations, to operate under specified conditions. Any firm permitted to mine must submit two sites to the Authority, which then decides which site to award to the firm and which to retain for its exploitation on behalf of the international community.

The authority would be funded from the sale of minerals under its control. The proceeds from the sale of minerals would first be used to fund the Authority and then would be shared among the needy Third World states including those exporting land-based minerals that might suffer from the competition of seabed mining. The major significance of the arrangement, from SPS point of view, is that it provides, for the first time, a global body with its own direct source of revenue. The international entity is technically no longer reliant on individual nation-state contributions. However, national contributions are needed to establish the Authority and it may prove difficult to make it operational without the support of the US, a major donor.

Only the US today remains among the major world powers opposed to the Treaty adopted in April, 1982. The US has declared its intention to abide by the treaty provisions except for those pertaining to deep seabed mining. The US wants modifications to benefit private mining companies. It wants priority in the first mining contracts to be assigned to a consortia of five Western companies dominated by US corporations, weighted voting power in the Authority, a US veto over proposed amendments to the treaty, and the return of mining sites not exploited by the Authority to private developers.

Certainly, differences exist between the Law of the Sea and the requirements of SPS. Under SPS, certain nations and perhaps corporations would come forth with large sums of capital, which is not the case for the Law of the Sea. Those putting up the money will want more control, whereas the poorer nations will be reluctant to have their energy supply under the control of their more affluent neighbors. The SPS organization must find a way to reconcile this conflict.

THE 1987 MONTREAL PROTOCOL AND LONDON MARCH 1989 MEETING[15]

These agreements have also set a precedent for cooperation—first to cut in half emissions of chlorofluorocarbons chemicals and then to totally ban them.

At those meetings, some countries posed special problems. China and India insisted that the richer nations subsidize their phase-out of chlorofluorocarbons, and the Soviet Union stated that it needed more scientific evidence before agreeing to a total ban.

With respect to SPS, it is possible that smaller developed countries would object to subsidizing China, a nation with a large population, development potential, and a major contributor to the CO_2 problem.

THE 1946 BARUCH PLAN[16]

This proposal on atomic energy is instructive for two reasons: its efforts to combine business and government interests in a monopoly as well as an effort to establish internationally based inspection and sanction powers.

The plan proposed to place the mining and milling of uranium as well as the possession and destruction of nuclear weapons in the hands of an international agency. Bernard Baruch drew up his scheme in part to accommodate the interests of a cartel, largely in the Belgian Congo, that controlled uranium in the international market. He did not believe control of uranium could work without their support, and he persuaded President Truman to build a combined public-private system of monopoly control. This aspect of Baruch's effort is interesting for the insights it offers into the problems created for SPS by the international energy companies and the producing nations, such as the Seven Sisters. The proposed agency also had verification powers, including the rights of intrusive inspection and sanctions. Baruch knew that the possession of these powers by a UN agency breached the principal of sovereignty and would be unacceptable to the Soviet Union. He nevertheless proceeded, and the plan died.

The recent INF Treaty indicates that the Soviet Union may not object to intrusive verification, but other nations might since it could be perceived as a limitation of the principle of sovereignty. Verification of the dismantling of baseload power plants would be needed. It might be possible to perform part of the verification with satellites. Sanctions would still be necessary, and they should not be subject to veto by any nation. As the controller of the world's electric power, the SPS organization would have sufficient clout to impose meaningful sanctions in a timely fashion.

THE 1959 ANTARCTICA TREATY[17]

This Treaty provides an example of an accomplishment to be emulated and a failure to be avoided. For over a quarter of a century, it has provided very tangible achievements in the areas of peace, science, conservation, the environment, and international on-site inspections. The unqualified positive accomplishment is in the areas of research, international cooperation, and, long before the INF treaty, intrusive inspections by US and Soviet teams of each others facilities for the verification of the peaceful uses of Antarctica.

The Treaty is built on a foundation of nation-states participation but is managed by the Antarctic Treaty System (ATS), a non-governmental body. ATS is made up of the Scientific Committee on Antarctic Research (SCAR), which, in turn, is governed by the Treaty, two accompanying protocols, and a set of recommendations. The problem is that when ATS was constructed, only 18 nations (Consultative Parties) were given full decision-making status under the Treaty. While the Consultative Parties acted in the spirit of international cooperation, they were representatives of their nations. An additional 17 nations have observer status at the biennial ATS meetings. Thus, the problem relates to the membership, not the structure.

The limited membership has raised questions of participation, and other nations want a greater involvement in the formulation and review of Antarctic policies. Today, no general agreement exists as to whether Antarctica is part of the international commons. For example, seven states maintain territorial claims. Many developing nations reject the idea that Antarctica should be managed by some countries to the exclusion of others. Many of these see the ATS as the exclusive preserve of the rich and technologically advanced countries. They assert that even if SCAR has performed a trusteeship role in protecting the environment of Antarctica, the interests should be defined by all nations, not just the Consultative Parties. The "question of Antarctica" today is on the UN agenda, and a debate is under way in the international community regarding the future management of the continent. The debate is over equitable management and use of Antarctica's resources. The management system is bound to change in the future as efforts are made to accommodate the interests of all nations and to manage conflicting pressures for resource development and environmental protection.

THE 1970 NONPROLIFERATION TREATY (NPT) AND THE INTERNATIONAL ATOMIC ENERGY AGENCY (IAEA)[18]

The NPT and its associated agency, the IAEA, provide a tangible model for safeguards against the diversion of civilian power-reactor programs to military purposes. It does so with an international treaty, the creation of an international agency, the IAEA, and a team of international experts who inspect and monitor the nuclear power plants of signatory nations under IAEA authority. The Treaty obligates signatory states to accept safeguards as laid down in a special agreement with the IAEA to ensure no diversion of nuclear materials to the manufacture of nuclear weapons. It included a promise by signatory governments possessing nuclear weapons and expertise to pursue nuclear disarmament and to assist non-nuclear signatories in developing nuclear power for peaceful purposes only. There have been numerous problems, but the inspection record and level of cooperation has improved over the years, and it serves as a model of what multilateral cooperation can accomplish.

The Treaty has two two major weaknesses. First, it allows some nations to remain outside the treaty's obligations and these nations tend to be those on the threshold of acquiring an indigenous nuclear-weaponscapability. Second, nations are legally allowed to make all preparations for manufacturing nuclear weapons except for assembling the warhead. This means that, with sufficiently advanced technology, it may be possible to implement a nuclear weapons option within a very short period of time, perhaps a couple of months. In both cases, the Treaty has failed to prevent proliferation.

Nonetheless, the Treaty's inspection system has remained a model for international cooperation, and at the time of the Chernobyl accident, the IAEA played a very critical role as a vehicle for communications and help. Since then, it has become the new vehicle for emergency notification procedures and assistance for a radiological emergency for all the nations of the international community.

OTHER EXAMPLES

Other examples include the U.N.'s Commission on Environment and Development, which has helped to focus attention on the global challenge, institutional gaps, and the need for new policy direction in ecosystems protection, energy choices, and the role of the international community in redefining security and managing the global commons. In focusing world attention on the greenhouse effect, it has examined national targets for emissions, though it leaves open the question of whether to require an equal reduction of CO_2 percentage or make the big polluters, such as the US and Soviet Union, reduce more. Although it has set goals, the decision on how to meet them is left to the individual countries. It has proposed penalties for noncompliance.

Other instructive examples can be found, but those given above offer at least the start of an anatomy for SPS and provide insights into the pattern of problems that will have to be solved for the creation of an effective SPS administration.

CONCLUSIONS

This paper is predicated on the assumptions that the greenhouse effect is real and that the SPS concept is a technically, environmentally, politically, and economically feasible way to resolve it. Previous study indicates technical feasibility. Economic feasibility is not dictated by the 11 trillion dollar price tag but

rather by the cost of feasible options to overcome the greenhouse effect. We do not have than information. It is anticipated that SPS will resolve far greater environmental problems that it creates. However, research is needed now if we want to be confident that the solution will not be worse than the problem.

Time is an essential factor due to global warming. At present, it is anticipated that a commercial SPS will be in operation in the year 2000, under NASA auspices. Perhaps that schedule should be accelerated. Probably the biggest hurdle to generating power for the world by SPS satellites is international cooperation. We have examined some historical models which encompass aspects of some of the problems SPS will encounter. None of these deal with the creation of an entity so important to a nation's energy supply. It was suggested that the funding could come from the defense budgets of the developed countries, but is the world ready to beat its swords into semiconductors? Has anybody got a better way to do it (What's your solution, brother)?

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CONFIDENCE BUILDING IN AND THROUGH FISSION AND FUSION ACTIVITIES

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ABSTRACT

The peaceful uses of atomic energy are most suitable for achieving worldwide confidence building. The reasons and some specific remarks are given. If we fail to help the public perceive the peaceful uses of atomic energy, the result will be a disaster for modern civilization.

The process of research, development, and implementation of the peaceful uses of atomic (or nuclear) energy—what is called fission and fusion activities in the title of this paper—is most appropriate for achieving worldwide confidence building.

The reasons are as follows:

1. In spite of the need for peaceful uses of nuclear energy, the world is facing difficulties in the public perception and acceptance of nuclear works and facilities.
2. The above difficulties are due to many factors, such as the two sides of nuclear energy—peaceful and military, the possibility of a large-scale reactor accident, the lack of understanding about radiation and radioactivity, and finally, emotion and egoism. Some of these factors are unique to nuclear-energy, but in other cases of public reactions, there are many facets similar to the above factors.
3. The Public concern about safety is at its highest, broadest and severest point ever, coincident with the highest life expectancy in history. Over-precaution and over-protection about certain things may sometimes spoil one's health. Nuclear energy is most definitely suffering from such a trend. As a result, a severe nuclear accident in any country results in severe damage worldwide no matter in what form the real physical effects reach other countries.
4. The huge science and technology efforts required for "fission and fusion activities" cannot be fully achieved by one country.

Explanations of some of the above factors are given below.

Since it is not the main subject of this paper to explain the many advantages of and the need for peaceful uses of nuclear energy, the author will only say that we believe nuclear energy is the best major energy source from many points of view, including the global environmental viewpoint in regard not only to the greenhouse effect but also to the small amount of waste.

Nevertheless, the opposition movements to the peaceful uses of nuclear energy seem 'unfortunately' to be increasing in number and extent throughout the world. The opposition movements have gained strength after the Chernobyl accident in April 1986.

The Chernobyl accident was the most severe reactor accident in history, but the report "The Radiological Impact of the Chernobyl Accident in OECD Countries," published in late 1987 by the Nuclear Energy Agency of OECD, mentions in the conclusion of the executive summary that "On the whole, however, these consequences do not raise any major concern for the health of the population in OECD Member countries. In particular, individuals in those countries are not likely to have been subjected to a radiation dose, in terms of effective dose equivalent, significantly greater than that received from one year of exposure to the natural radiation background. As a consequence, the lifetime average risk of radiation related harm for the individual members of the public has not been changed to any significant extent by the accident." Mr. H.K. Shapar, Director General of the NEA, introduced this report and distributed copies translated into Japanese at a press conference in Tokyo, April 1988, but only a few newspapers devoted any space at all to it, and then without mentioning the essential point of the report. On the contrary, many quasi-documentaries in newspapers and magazines in Japan have exaggerated the consequences of the Chernobyl accident.

It is evident that the peaceful uses of nuclear energy, including all the accidents that have so far happened, have a much better safety record than that of other systems, such as traffic and housing systems, that have been accepted for a long time by the public.

The technology of the present light- and heavy-water reactors is fairly matured, but there are many R&D items that must be undertaken for new types of reactors, fuel-cycle technologies, radioactive waste managements, etc.[1] Those are not dealt with in this paper.

The uses of atomic energy have two sides, peaceful and military. Any technology may have these two sides, more or less, but the atomic bomb is extreme. Because of this, it is natural that some people have a sort of allergy to atomic energy. However, we must make every effort, no matter how difficult, to achieve a fair public perception and acceptance of the peaceful uses of atomic energy. Because of the two sided nature of nuclear energy, the Non-Proliferation Treaty, nuclear-material safeguards, and physical protections have been invented, which may be categorized as policy-based technological measures for confidence building.

The speech "Atoms for Peace," made by US President Dwight D. Eisenhower on December 8th, 1953, at the United Nations, led to the organization of the International Conference on the Peaceful Uses of Atomic Energy (The Geneva Conference) and to the creation of the International Atomic Energy Agency (IAEA). Since then, international cooperation in the atomic energy field has been steadily growing through the IAEA, the NEA of OECD, bilateral and multilateral agreements, and so on. One of the basic motivations of international cooperation comes from the understanding, as mentioned earlier, that such huge science and technology as "fission and fusion" cannot be fully achieved by one country.

As long-standing international cooperation in nuclear-data activities[2] is a typical example. Cooperation in the field of nuclear safety has scaled up including large hardware changes, since the Three Mile Island accident. New aspects of cooperation appeared after the Chernobyl accident. One remarkable outcome has been the inaugural meeting of the World Association of Nuclear Operators (WANO), held in Moscow May 15, 1989. In the field of fusion, international cooperation has prevailed since the very early stages of the R&D.

The existence of radiation and radioactivity is a part of nature itself. Only an excess of radiation is unhealthy, which is similar to an excess of salt or sugar. Although the biological effect of a low radiation dose is not yet fully understood, it is certainly not practical to worry about the effects of radiation levels that are within the range of normal local fluctuations of the natural background. Research on radiation hormesis should also be promoted.

It is commonly mentioned in commentaries dealing with safety that there is no absolute safety. On the other hand, "safety first" is, of course, an utterly fundamental rule. But it should be noted that "safety first" is carried out under certain conditions pertaining to the task. It is difficult to convince the public of the safety level of given large systems with numerical data from a scientific assessment. And it may be better explained by comparing it with other familiar systems already well accepted by the public.

In any event, it is necessary that there exist a certain level of confidence among the public, specialists, and authorities. To assist in this, it will be useful to have, for example, an international database on all kinds of large accidents, including the nuclear ones, say in the last 30 years, with assessments on the actual damage and consequence of each. The database must be easily accessible and understandable by the public. The compilation work for the above may require fairly large efforts, including translation from professional databases and reassessments to a certain extent as occasion demands. The existence of larger accidents should not be used to excuse smaller accidents of course; moreover, the risks and benefits of a particular matter must be judged from viewpoints as broad as possible, depending on the importance of the matter. Hence, a broad knowledge of actual accidents is requisite for the above judgement. To further mitigate unreasonable public fear, the author would also suggest adding another database, that is, a toxicology database that includes radioisotopes.

In this age of information flooding, a false or groundless image of a certain matter can be assembled intentionally by using reported but fragmented facts and, quite possibly, false reports. The public may accept this unfair image as reality because of the many "facts that are referred to." To cope with such things, the public should always be provided with reliable information.

If we fail in the achievement of a realistic public perception of "fission activities," it will result in a disaster for the global-energy and environmental problem and, subsequently serious difficulties will arise in the public perception of any other new large technology system that is difficult for nonprofessionals to understand.

The wording in the title of this paper was chosen simply to correlate it clearly with the title of the "Fission workshop." "The peaceful uses of nuclear energy" usually includes not only "fission and fusion" but also the use of radiation, etc.

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THE SOVIET-AMERICAN GALLIUM EXPERIMENT—SAGE

by

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It is a great pleasure for me to have been asked by Louis Rosen to tell you about the Soviet-American Gallium Experiment (SAGE).[1] This undertaking is a multi-institutional collaboration among scientists from the Institute for Nuclear Research, Moscow (INR), Los Alamos National Laboratory (LANL), and several U.S. universities. Its purpose is to measure the number of low-energy electron neutrinos emitted from the Sun that arrive at this planet. As such, it is an extremely important experiment, touching on fundamental physics issues as well as solar dynamics. In contrast to the strategic overviews, plans, and hopes for international collaboration presented earlier today, SAGE is an ongoing working effort with high hopes of producing the first measurement of the Sun's low-energy neutrino flux.

It should be pointed out that there are several international physics collaborations involving U.S. and Soviet scientists at the large accelerator installations throughout the world. These collaborations seem natural to physicists as the scale of research gets ever larger, requiring ever more resources and hence larger collaborations. Further, much physics research lies solely in the realm of basic research so that governments feel easier about entering into such potentially harmless collaborations. Indeed, a variety of contacts between the U.S. and U.S.S.R. scientists interested in nuclear and particle physics goes back to the nineteen fifties. These contacts have continued with only minor interruptions since then. Over the past two decades the principal oversight of these activities has been through the Joint Coordinating Committee on the Fundamental Properties of Matter, supported by the DOE in the U.S. and the State Committee for Atomic Energy in the U.S.S.R. The Academies of Science of both countries have been very helpful and supportive. Each collaborative venture has some distinguishing features; in the case of SAGE, the unique aspects are the collaboration between Soviet scientists and scientists at a DOE weapons laboratory and the fact that the experiment is carried out in a remote region of the U.S.S.R. The particular problems caused by each of these features will be discussed below.

Let me briefly indicate why SAGE is important and how it is being done. The Sun is a gigantic fusion reactor where hydrogen is processed into heavier nuclei with the release of vast amounts of energy. The principal energy-producing reactions are

$$p + p \rightarrow d + e^+ + \nu_e \tag{1}$$

$$p + p \rightarrow np + e^+ + \nu_e \ , \tag{2}$$

which lead to a net effect of

$$4p \rightarrow {}^4\mathrm{He} + 2e^+ + 2e_\nu \ .$$

Most of the energy production occurs at the center of the Sun where the high temperature of some ten million degrees facilitates the nuclear reaction rate. The energy created there by these reactions takes the order of one million years to reach the surface of the Sun where it is then radiated away. However, many of the most important reactions, such as those indicated in Eqs. (1) and (2), are accompanied by the release of neutrinos. Neutrinos are very light particles that interact very weakly with matter. It is fortunate for us

that this is the case because right at this instant we are being bombarded by 10^{10} (ten billion) neutrinos per sec per cm^2 from the Sun. Figure 1 shows a theoretical spectrum of the various neutrino fluxes expected based on our idea of how the Sun works. Because the neutrinos are so weakly interacting, detecting them is a very difficult proposition. In fact, just two measurements of the solar ν flux have been made to date and these have been of only the highest energy component of the neutrino spectrum from the Sun. Though very different techniques are used, both experiments[2,3] agree that the solar neutrino flux is at least a factor of two lower than had been expected on our model of how the Sun works. The weakly interacting property of neutrinos that makes them difficult to detect, however, has a positive side to it. It provides a way to detect what goes on in the center of the Sun. No other signal can do this! As can be seen from Fig. 1, the high-energy portion of the solar neutrino flux ($E_\nu > 5$ MeV) is a small fraction of the total flux and it is possible that details of the model of how the Sun works, which are incorrect, can account for the observed shortfall. On the other hand, it is also possible that the factor of 2 to 3 shortfall occurs because some fundamental physics input is wrong. For example, the current description of the physical world would not allow the neutrinos emitted from the Sun to change their type while they are in transit to the Earth, but this interesting possibility is theoretically conceivable. If some of the electron neutrinos emitted by the Sun were to change into either muon or tauon neutrinos, they would have escaped detection in the solar neutrino experiments mentioned above. Thus, the shortfall in the number of observed solar neutrinos can be due to either an incorrect detail in the model of the Sun or in a fundamental issue of neutrino physics. This latter aspect is very important because it would represent the first observation of an inadequacy in the present-day Standard Model. The Standard Model is a remarkable synthesis of the fundamental physics and has passed all experimental tests to date. The low-energy neutrinos that SAGE can measure are produced by the nuclear reactions that dominate the energy production within the Sun. Thus, there can be little doubt of the number of these neutrinos that are generated within the Sun. A shortfall in this portion of the spectrum would require changing our view of the physics of neutrinos.

SAGE measures low-energy neutrinos by detecting the radioactive decay of the isotope ^{71}Ge, which is produced via the reaction $\nu + {}^{71}\mathrm{Ga} \rightarrow {}^{71}\mathrm{Ge} + e^-$. That is, the neutrino scatters from a gallium nucleus, with the neutrino changing to an electron and the gallium nucleus being converted to a germanium nucleus. Figure 2 shows a simple diagram of the processes involved. The Ge is extracted from Ga and is chemically altered into a gas GeH_4 (germaine). The germaine is fed into a counter that detects the radioactive decay of ^{71}Ge as an electronic pulse. The difficulty in the experiment arises because of the very low rate at which solar neutrinos can produce ^{71}Ge. In fact, in the 60 tons of gallium that SAGE employs, approximately 2 atoms of ^{71}Ge will be produced per day. These few atoms must be extracted from the 5×10^{29} atoms of Ga. Surprisingly, the technology to do this is all at hand and a measurement of the neutrino flux with better than 10% accuracy seems possible. In order that other more strongly interacting components of cosmic radiation do not create Ge, the 60 tons of Ga must be placed deep underground, thereby being shielded from all cosmic rays except the very penetrating neutrinos.

The Soviet scientific team has provided the essential elements for the experiment. They have provided 60 tons of Ga, an adit some 4 km deep into Mt. Andyrchi in the Caucasus mountains, some 50 km from Mt. Elbrus. In addition, the INR has developed a full underground laboratory (Fig. 3) at this 4-km depth where the extraction and counting of ^{71}Ge takes place. By any accounting system, the Soviet investment in this experiment is in excess of $100 M. For our part, we provide some scientific expertise, some high-tech electronics, and a number of small computers for taking and analyzing the data. If the Ge extraction procedure becomes sufficiently routine, then we would also take on the task of putting it completely under computer control. Thus, our role, while small, is important. We bring in crucial elements of western technology that are important in making such a difficult experiment believable to the worldwide scientific

community. I believe that our Soviet colleagues could do this experiment without us, but we are in a position to enhance the credibility and general acceptability of the end result. I am not sure, but I believe our more competitive disposition has helped to push forward the schedule for results from this experiment. It remains to be seen whether or not this contribution proves to have been really helpful.

A brief historical note on how the collaboration came about: In 1985 LANL had been involved with Brookhaven National Laboratory (BNL) in putting together a proposal for a U.S. collaboration to carry out a rather similar gallium experiment using $GaCl_3$. Our proposed experiment would have used 30 tons of Ga, which had a market value of approximately $15 M. Though the LANL/BNL joint proposal enjoyed an enthusiastic and supportive scientific review, it was not funded. This was largely due to the fact that there really is no federal agency with a clear charter for funding this kind of research (a genuine shortcoming in the U.S. system). During the process of preparing the proposal in 1985, we were visited by Volodya Gavrin, a scientist from the INR who is in charge of the gallium experiment and his colleague, Anatoly Kopylov. We exchanged ideas, information, and they then went on their way. When they heard of the lack of positive response to our proposal on the part of the U.S. government, they invited us, and other interested institutions in our proposed collaboration, to join with them in their experiment. Thus, in November 1986 a memorandum of understanding regarding general issues and interests in neutrino physics was drawn up and signed by representatives of both U.S. and U.S.S.R. institutions. This document has served as the basis of our continuing collaboration. George Zatsepin of the INR and Albert Tavkhelidze, the then Director of the INR, were instrumental in developing this agreement. Each year a set of specific goals and obligations for the INR and the U.S. collaborators is drawn up. We are now in our third year. This format works well in spite of our continued inability to foresee the delays and snags that unusual procurements and protective embargoes place on procuring and sending materials to the U.S.S.R.

The present status of SAGE is that the underground laboratory is essentially complete and in full use. Thirty tons of gallium have been placed in five reactors, each of which holds six tons of gallium. Extractions of germanium from these 30 tons have gone on for several months with the result that the background germanium that was created by cosmic rays on the surface has now been removed and real data-taking can start this fall. The full 60 tons of gallium should be installed and purified by sometime in early 1990.

Let me now make a few observations on how our collaboration works that may be useful for those who encourage or oversee such enterprises. First and foremost, the collaboration works well scientifically and socially. Together we are making steady progress toward an important scientific goal that would range from difficult to impossible (for us) if our countries went about it separately. I also believe that our participation has significantly advanced the schedule for getting results out of the experiment. The U.S. scientists have little desire to make a career out of this particular experiment, though the experiment is doubtless of great importance and its accuracy can be continuously refined, perhaps leading to new scientific insights. The U.S. collaboration believes that the most important short-term goal is to proceed to get a 10% measurement to determine if the basic physics is correct.

It is extremely gratifying to see the degree of support and interest that this experiment generates. There have been two articles in the *New York Times* about SAGE as science writers find the collaboration's work scientifically significant and the nature of the collaboration to be interesting at the political level. The support of the Division of Nuclear Physics at ER/DOE has been outstanding and the National Academy of Sciences has always had a supportive interest.

The experience of working together has brought to members of SAGE more than just the normal pleasures of working on an interesting scientific project. We have come to understand each other in a

way that can only be developed within a group of people working together on a common and difficult goal. We have come to understand the problems and difficulties in our respective systems as well as those aspects of our societies that are useful and supportive of science and scientific objectives. I was in the Soviet Union at the time of their elections to the Council of Delegates and was impressed by the open and extremely democratic nature of those elections. This was as true for the election of candidates from the Soviet Academy as for the elections in the country at large. There is no doubt but that genuine scientific and technical collaboration is one of the best modes I know of for mutual confidence building. The question has come up at this conference from time to time whether or not confidence-building measures could as well apply to humanistic and artistic ventures. I see no reason why that should not be the case, but I believe it is important that the joint venture be seen as sufficiently difficult that the collaborative group feels the need to work jointly together to realize eventual success. Actually, in this regard, some external criticism and expression of doubt about the outcome of the project can be useful.

There are, of course, down sides to any endeavor and this one is no exception. Our progress is always slower than we had hoped. We would like to have been at our present status one year ago. This is probably a reflection on the general optimism, if not ego, of scientists and physicists in particular. However, without these qualities, projects as difficult as SAGE would probably never be undertaken.

It is also a considerable problem that the members of the scientific team are really unknown to one another and come out of different cultures and receive very different amounts and forms of external support. As a result, completely unrealistic demands are often made on both sides. When my Soviet colleagues learn of the total budget of the Los Alamos National Laboratory, they cannot understand why we have difficulty in coming up with $200 k for a mass spectrograph on two month's notice. Indeed, so far as I can tell, procurements in the U.S. are made with a great deal more bureaucratic oversight than those in the U.S.S.R. By the same token, we have a hard time understanding the transportation problems our colleagues face in getting us down to Baksan. It not only requires getting air passage from Moscow to Mineral a Vody but requires that someone take the better part of a day to drive out to Mineral a Vody from Baksan to pick us up and return to Baksan, so it is really a pain-in-the-neck for all concerned.

The unusual aspects of this scientific collaboration are, as I said earlier, the fact that Los Alamos is a weapons laboratory and that the experiment is carried out in the U.S.S.R. These two features have produced their share of problems. The U.S. has tight restrictions on visitors from sensitive countries to our defense laboratories. Restrictions apply to such matters as the length of stay (21 days/year). The amount of paperwork involved in getting approval for these visits is very cumbersome and acts as an impediment to such visits. As it is necessary to send specific pieces of experimental equipment to the U.S.S.R., we are often required to obtain export licenses. It is not that any of these tasks is particularly onerous, but they require people and time. We are not aware of receiving any special help in these matters. I consider this surprising, as there is general support from DOE/ER for such enterprises, but when it comes down to obtaining approval for Soviet visitors, approval for our own travel to the U.S.S.R., and export licenses, there remains a formidable bureaucracy with which to deal. It seems that we face it alone and with a fresh start every time. So far these barriers have not prevented progress, but they slow things down at the rate of about 3 months/year.

My suggestions for improving such collaborations in the future would be to get all the interested parties—the scientists, the scientific institutions, and the Federal agencies that provide the support—together at the outset of the collaboration. At that time clear and reasonably binding agreements can be reached on resources and security issues, if any. It would also be useful to agree on a format as to how the progress of each group in the collaboration is to be measured and communicated. In a society like the U.S., we have

become accustomed (even jaded?) to writing plans and reporting the progress with respect to those plans on a regular basis. This practice is apparently not universal, but it appears essential for the smooth and orderly functioning of an international collaboration where simpler channels of communication are not yet firmly in place and where each side is somewhat uncertain as to the schedules and other priorities within the respective groups and institutions. In addition to a general framework that outlines the general goals, areas of responsibility, and terms of information and data exchange, there needs to be a regular meeting that occurs at least once a year to formulate in detail the specific milestones and resource commitments over that period.

Therefore, it appears to me that collaboration on scientific projects is a very powerful instrument for mutual confidence building. The process of agreeing to work on a specific project and then working out the details at the scientists' level has the capability of showing the way of how to deal with even larger undertakings. If my experiences with SAGE are any measure, you should have a great deal of confidence that such undertakings are likely to be successful and mutually enriching. In fact, our collaboration on SAGE has led to a much wider collaboration between INR and LANL. We now exchange people and information on a wider range of issues in nuclear and particle physics, as well as our providing assistance to their commissioning a large meson factory at Troitsk that is similar to LAMPF at Los Alamos. The increased interest in environmental issues in the Soviet Union has led them to become very interested in the regulations and procedures that are employed at LAMPF and to see how they can be adopted for use at Troitsk. It appears that the time is ripe and the prospects bright for further collaboration.

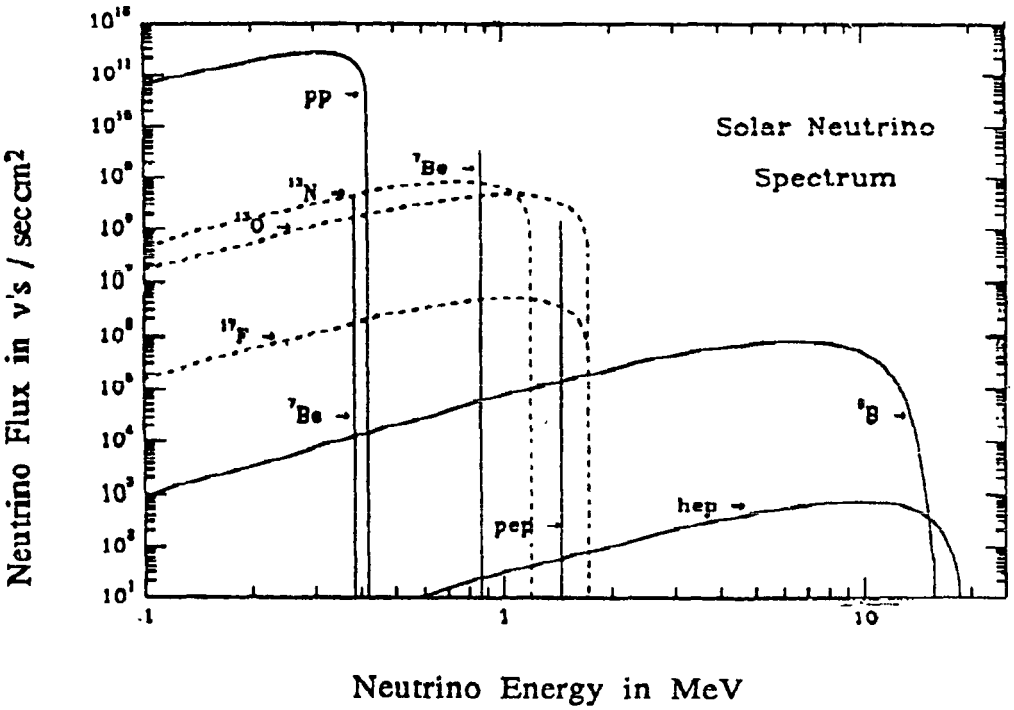


Fig. 1. Predicted spectrum of the flux of solar neutrinos measured at the Earth.

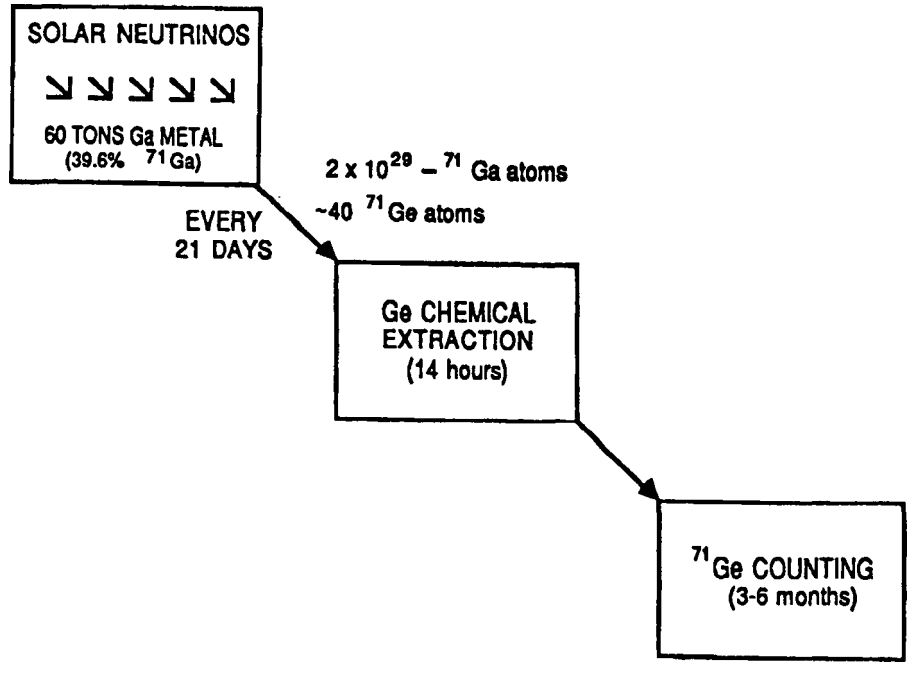


Fig. 2. Simple diagram of the principal steps in the production of ^{71}Ge from ^{71}Ga via solar neutrinos and the removal of the few ^{71}Ge atoms from the vast number of Ga atoms.

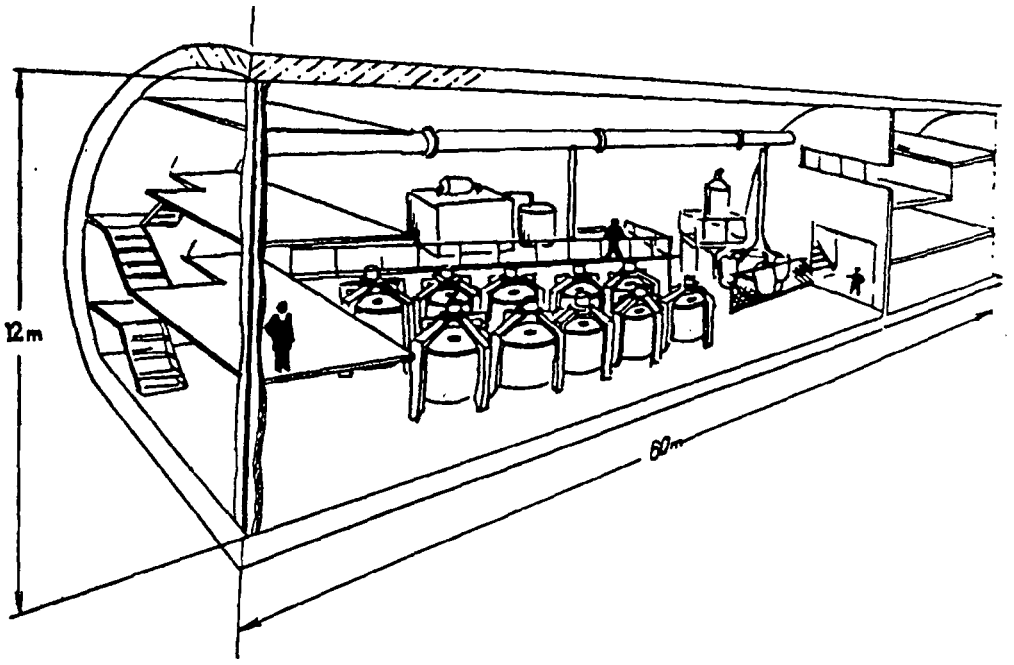


Fig. 3. Simple diagram of underground vault for the SAGE experiment. This vault is 4 km into the side of Mt. Andyrchi. The ten large vessels shown in the diagram hold the 60 tons of metallic Ga in a liquid state.

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COMPARATIVE ANALYSIS OF MASS FOREST AND "NUCLEAR" FIRES

by

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The modern era of studies of nuclear war climatic consequences started with the paper by Crutzen and Birks (1982). Taking into account data of the US Forest Service, they estimated the possible area of forest fires initiated by nuclear explosions to be 10^6 km^2, which is about 20 times the mean area of annual forest fires and corresponds to 4% of the temperate and boreal forests in the Northern Hemisphere. They assumed the density of the dry biomass in the forests to be about 20 kg m^{-2} from which about a quarter is burned off, and from 4 to 7.5% of the burning matter goes into smoke, and as a result 200-400 Tg of smoke is injected into the atmosphere. Crutzen and Birks implicitly assumed that after two or three weeks the smoke would cover more or less uniformly half of the Northern Hemisphere ($125 \cdot 10^6$ km^2), about 10% of the smoke would be left in the atmosphere, and its mass in a unit column would be 0.1-0.5 gm^{-2}. Using the mass extinction coefficient of the solar light as 4-9 mg they obtained the reduction of sunlight at the surface during summer noon in the range of 2 to 150 times.

Since 1982 these results have been analyzed many times. NRC Report (NAS 1985) estimates the area of forest fires as $0.25 \cdot 10^6$ km and the smoke production as 3% which gives 30 Tg of smoke. Crutzen et al. (1984) give a value close to this one. The review of smoke produced by nuclear wildfire one can find in Chapter 3 of Pittock et al. (1986). It looks now plausible that the main sources of sunlight absorbing aerosols would be city fires and industrial fires. Nevertheless, there is still a very considerable interest to the studies of origination and development of large forest fires, to the production, lofting up and spreading of smoke because these studies may teach us much about fires in general. Based on information about the Siberian fires of 1915 we will discuss what is common and what is the difference between city and forest fires.

Large forest fires start when the so-called index of fire danger

$$N = \sum_n t \cdot d \qquad (1)$$

is large enough. Here n is the number of days without precipitation, t is the temperature in °C and d is the humidity deficit in mbar; t and d are measured at 1:00 PM, local time. According to Tkachenko (1955) forests do not burn if $N < 300$. The forest "fire maturity" starts for $N > 4000$. We present here data on maximal values of the index N which were obtained during 1891-1966 at the meteorological station Yeniseysk near the mouth of the river Angara. During this period values of $N_{max} > 5\,000$ were observed for 40 individual years, $N > 10\,000$ was observed 9 times and in 1911 and 1915 N_{max} reached, correspondingly, 18 300 and 15 100. In these two years 100% of the dark coniferous forests were mature for fires (Furgayev, 1970). The year 1915 had the largest forest fires in the history of Siberia for the whole period of the instrumental observations. We will shortly describe them after Shostakovich (1924, 1925 a,b), who was at the time an employee, and since March 1917 the director, of the Irkutsk Magnetic and Meteorological Observatory.

To obtain information about the fires of 1915 the Irkutsk Observatory sent 500 questionnaires and 350 of them were answered. The answers may be regarded as reliable because, before the revolution, all the

staff of meteorological observers in Yakutia and east to Baikal were always from the intelligensia, i.e., from political convicts (Shostakovich, 1924). The same was true in all other regions of Siberia. Shostakovich (1924, 1925 a) presented data of 27 Siberian meteorstations embracing a territory of $4 \cdot 10^6$ km^2. Almost everywhere at this area from May to August precipitation was considerably below normal. From mid-June until mid-July, many regions of Central Siberia experienced no rain during 13-36 days, and from the end of July until mid-August there was a second dry period, 16-36 days long.

One hundred forty-two people out of the questioned ones gave answers allowing one to reconstruct details of fire spreading and smoke spreading in the atmosphere. According to their information the fires were observed during 50 days in June-August at the area between 52° and 70° N, 63° and 112° E which comprises 1.8 million km^2. The most intense fires were between the Angara and Nizhnyaya Tungouska rivers, in the upper half of the Ob river, and along the right bank of Yenisey in its lower part. The area of the "fire consumed forest" was about 1410 km^2 (Shostakovich, 1924, 1925 a). This value we use in the following discussion.

Now we shall try to estimate the amount of the smoke produced. If we use the same assumptions as in NAS (1985) we obtain the result that $0.14 \cdot 10^6$ km^2 give 17 Tg of smoke. On the other hand Shostakovich assumed that in this area, half of the wood, or $1.6 \cdot 10^9$ m^3, was burned. The specific density of pinewood is 500 kg/m^3 (Tkachenko, 1955) and with a smoke production rate of 3% (NAS, 1985), we would obtain 24 Tg of smoke. These estimates one should evidently consider as a lower limit for the smoke from the fires of 1915 because ground litter was not taken into account here as well as smoke from smaller fires in other regions of Siberia.

As a result of large smoke injection into the atmosphere, visibility was strongly reduced. According to data from questionnaires, visibility did not exceed 100 m in an area of $2.8 \cdot 10^6$ km^2, it was between 25 and 100 m in an area of $2.2 \cdot 10^6$ km^2 and between 4 and 25 m in an area of $1.8 \cdot 10^6$ km^2. We assume for each of the smoke gradations corresponding to a visibility distance $\ell_1 = 100$ m, $\ell_2 = \sqrt{25 \cdot 100} = 50$ m, $\ell_3 = \sqrt{4 \cdot 25} = 10$ m. We shall assume that ℓ_i is determined in analogy with the meteorological visibility distance as

$$\ell = \frac{1}{k} \ell n \frac{1}{\varepsilon} \text{ or } \varepsilon = exp\,(-k\ell). \tag{2}$$

where k is the light-extinction coefficient, in m^{-1}, and ε is the sensitivity threshold of the human eye, which depends considerably upon the illumination τ, see Table I, constructed using the data of Matveyev (1984).

Table I

The dependence of eye contrast sensitivity threshold on illumination

Illumination conditions	τ, lux	ε	ε'	ε''
Day	$3\text{-}4 \cdot 10^4$	0.05	0.05	0.05
Full Moon	0.25	0.20	0.30	0.35
First (last) quarter of Moon	$3\text{-}4 \cdot 10^{-2}$	0.50	0.39	0.50
Moonless night	10	0.60	0.60	0.91

The dependence in the Table can be approximated as

$$\varepsilon = 1 - exp\,(-0.28\tau^{-0.17}) \approx 0.28\,\tau^{-0.17}. \tag{3}$$

Results of calculations of ε by the middle part of eq.3, ε' and its simplified variant, ε'', (right approximate equality in (3)) are also presented in the Table, where, in the case of the range 3-4, we took 3.5. The illumination of the Earth's surface is determined by the relation (see, e.g., Matveyev, 1984)

$$\tau = 100\,F_\Sigma\,, \tag{4}$$

where F_Σ is the flux of the total solar radiation at the surface. To estimate the value F_Σ we use eq. (3.3) from Golitsyn and Ginzburg (1985). For the typical value of the single scattering albedo $\omega = 0.9$ for the forest smokes and a Sun zenith angle of 60° we obtain

$$F_\Sigma = F_{\Sigma o}\,exp\,(-0.4\,KH)\,, \tag{5}$$

where $F_{\Sigma o}$ is the flux of the total solar radiation in the absence of smoke and H is the thickness of the homogeneous smoke layer.

Assuming that in the absence of smoke we have the usual daylight illumination and using the linear approximation of eq. (3), we obtain a simple expression for estimation of the vertical optical depth of the smoke layer

$$\tau = \sigma m = kH + \frac{-\ell n\,\varepsilon_o}{0.07 + \ell/H}\,, \tag{6}$$

where $\sigma = 4\mathrm{m}^2 \cdot \mathrm{g}^{-1}$ is the mass light-extinction coefficient for the smoke (NAS 1985, Pittock et al., 1986) and $\varepsilon_o = 0.05$ is the eye-sensitivity threshold at daylight. In the derivation of this formula we assumed that the smoke is homogeneous in the horizontal and vertical and occupies a layer from the surface up to altitude H.

If the smoke is in small quantity and behaves like a passive tracer, then it stays mainly in the planetary boundary layer, i.e., in the lower 1-1.5 km. At a high rate of burning, due to additional buoyancy, it may go up another kilometer or two. When the heating of the smoke becomes noticeable the height of the smoky layer starts to grow approximately as (Ginzburg et al., 1985)

$$H^2(t) - H^2(0) = \frac{2}{\Delta\gamma}\int_o^t \frac{\Delta F}{\rho\,C_p}\,dt'\,, \tag{7}$$

where $\Delta\gamma$ is the difference between adaibatic and actual temperature gradients, ΔF the total heat influx to the layer, ρ the air density and C_p its specific heat. If $\rho C_p = 1300^{\tau}/\mathrm{m}^3\mathrm{k}$, $\Delta\gamma = 3.3\ \mathrm{K\,km}^{-1}$ and $\Delta F = 120\ \mathrm{Wm}^{-2}$, we obtain a vertical velocity dH/dt of about 3 $\mathrm{cm \cdot s}^{-1}$ and this velocity decreases with altitude.

Large forest fires usually start in anticyclonic conditions when in the atmosphere above the palentary boundary layer there are large-scale descending air motions with velocities up to several cm s^{-1} (Palmen and Newton, 1969). Therefore, large smoke formations from natural fires seldom ascend higher than 3 to 5 km.

In most cases smoke is concentrated in the lower two kilometers and with strong descending movement the smoke could be at a lower altitude. Using the data by Shostakovich (1924, 1925 a) and eq. (6) we find for H = 2 km the mass of smoke is 50 Tg and for H = 1 km it is 40 Tg. These results can be considered as upper limits because it is not clear whether reduced visibility was observed in the whole territory simultaneously. It is also possible that the eye-sensitivity threshold is reduced somewhat in such unusual conditions. Optical parameters of the smoke also may require specification.

Nevertheless, one may accept that during the summer of 1915, over Siberia, a large smoke cloud was formed with the mass of smoke in the range of 20-40 Tg. This is comparable to the estimate of the amount of smoke from "nuclear" forest fires (NAS, 1985, Pittock et al., 1986). The smoke of 1915 was, presumably, mainly in the lower parts of the troposphere. However, this is not always the case for the smoke of forest fires. Better documented smokes of September 1950 from Alberta, Canada, forest fires were observed over the eastern US in the layer between 2-6 km, causing substantial darkness and a temperature fall of several degrees Celsius (see NAS, 1985, Smith, 1950).

Our calculations using a radiative convective model show that the presence of smoke in the lower troposphere changes the mean temperature of the surface very little. Cooling starts only for optical depth $\tau > 5$, see Figure 2.

If part of the smoke ascends into higher layers, surface cooling depends much more strongly on the smoke optical depth. This is illustrated by curve 2 in Figure 2, which was calculated using the assumption that 20% of the smoke was lofted into the upper troposphere (between 600 and 200 mb). This agrees with observations in North America in late September 1950 when a temperature drop of 4-6° C was observed in the Washington, D.C., area (Smith, 1950).

Note that when meteorological conditions allow large smoke clouds to come out of the descending-motion area, smoke can spread over thousands of square kilometers and occupy an area hundreds of times larger than the area of fire (NAS, 1985, Grigoryev and Lipatov, 1978). Shostakovich's data show that the smoke-covered area was only about 50 times larger than the area of main fires, which presumably could be caused by a strong anticyclone leading to large density of the smoke veil and its small vertical development.

Such a layer of smoke may not cause a large decrease of the near-surface air temperature, but could decrease temperature contrasts between day and night. To illustrate this we present in Figure 3 the day temperatures (at 13 hr) and minimal night temperatures for the meteorological station Yeniseysk, near the mouth of the Angara River, during August 1915 (Irkutsk, 1917). In the lower part of Figure 3 we present qualitative data on the meteorological phenomenon of "dry fog," taking into account relative intensity of the phenomenon. During all days from 5 to 28 August the observer noted overcast cloudiness, and besides this he noted "dry fog." It is possible that the overcast cloudiness and "dry fog" were smoke clouds, the latter being for cases when the smoke was low and consisted of very small particles. Figure 3 shows that if smoke is in smaller quantities and is not in the surface layer, the difference between day and night temperatures reaches 20°C. If "dry fog" increases, the difference is strongly reduced and, e.g., on August 17 it is less than 2°C. The day and mean daily temperatures are reduced during these episodes.

It is worthwhile to note that the reduction of day temperatures and increase of night temperatures act suppressively on vegetation, especially during crop maturation (Svirezhev et al., 1985). This may explain small and late grain crops in 1915, according to the local press of the time.

Our attention to the problems of large forest fires, in particular to Siberian fires of 1915, was again drawn in March 1986 by Carl Sagan. He told us that a letter of Seitz (1986) was circulating in the USA in which this author proposed those fires as a means for validation of "nuclear winter" models. We describe

here estimates obtained with a model which shows a large cooling of the Earth's surface after injection into the atmosphere of the absorbing smoke from the fires of nuclear war in good agreement with other models of the phenomenon (see Pittock et al., 1986, NAS, 1985). This same model also shows that one should not expect any appreciable changes of the surface air temperature during large forest fires, even as large as the fires in Siberia in 1915, due to the following reasons: 1) the smoke of such fires absorbs only weakly the solar radiation and its single-scattering albedo is only $\omega = 0.9$; 2) smoke often stays in the lower troposphere, which may even lead to some heating of the surface air if the amount of smoke is not very large; and 3) the amount of this smoke, more precisely its density, is not large enough to cause appreciable cooling.

At the same time, this study demonstrates once again the applicability of simple models to the description of sufficiently subtle phenomena, such as the influence of smoke from large forest fires on the thermal regime of the atmosphere and the surface. This reinforces our belief in the results of such models on the catastrophic consequences of nuclear war.

The authors thank Professors C. Sagan and Yu. M. Svirezhev for useful information and discussions, N.N. Veltishchev for calculating the results presented in Figure 2, many staff members of the Institute of Forest and Wood in Krasnoyarsk, the Institute of Geography in Irkutsk, and Irkutsk Natural Museum for help in obtaining the necessary data.

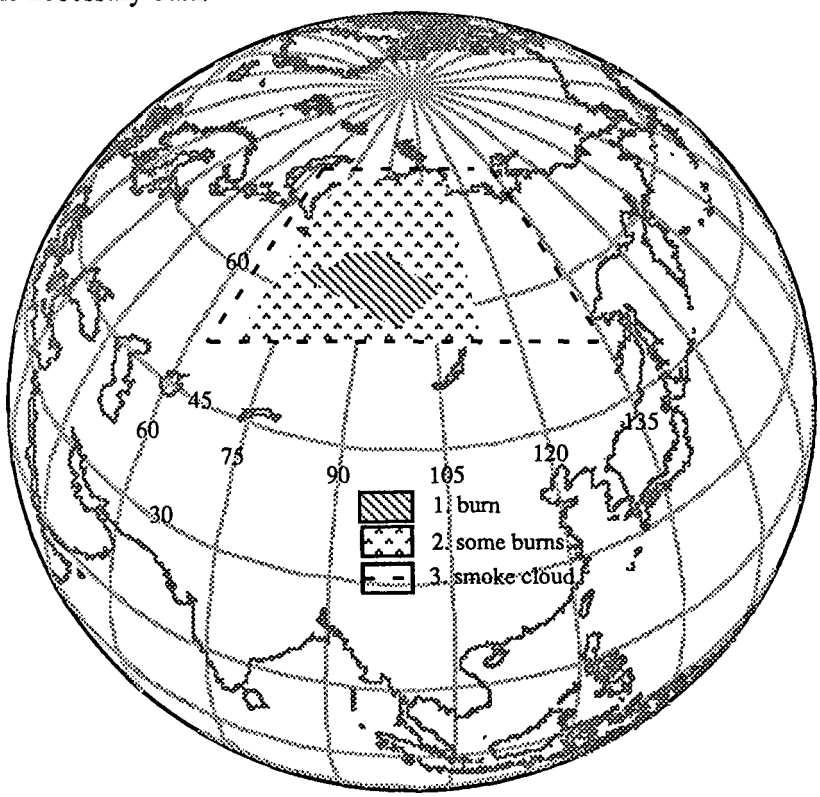


Fig. 1. Map of Siberian forest fires in 1915. 1 denotes the region where much of the forest was burned, 2 is the region of some burns, the dashed line 3 shows approximate boundaries of the smoke cloud.

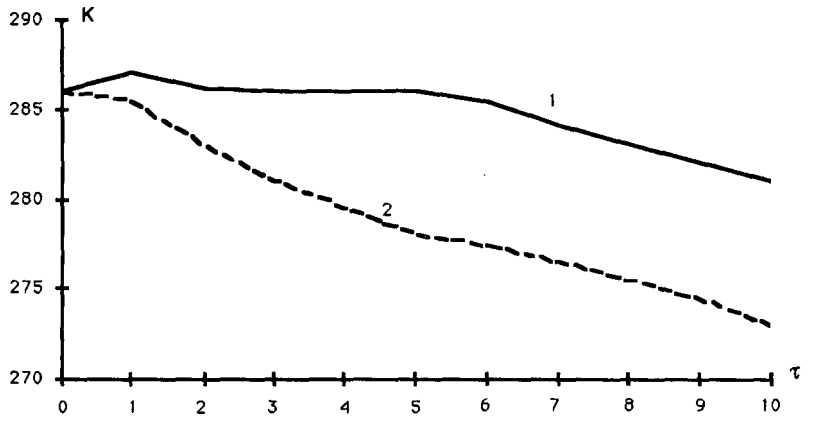


Fig. 2. Temperature of the land surface in dependence on the optical depth of the smoke layer; curve 1 corresponds to all smoke in the lower troposhere (100-600 mb); curve 2—when 80% of the smoke is in the lower troposphere and 20% in the upper troposphere (600-200mb).

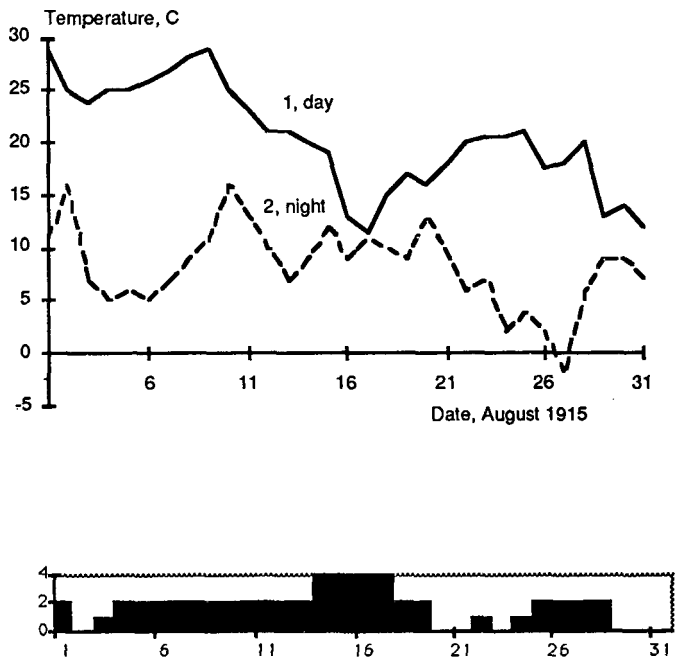


Fig. 3. Temperature at daytime (13:00 hr)—solid curve, and minimal night temperature, dashed curve, for August 1915 at the meteorstation Yeniseysk (58°N, 92°E). The lower part presents relative intensity of the "dry fog," presumably smoke.

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GEOTHERMAL ENERGY: AN INTERNATIONAL RESOURCE

by

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SUMMARY

The heat of the planet's interior ascends in certain discernable trends around the globe. Above 10 000 foot depths this energy is being recovered as an additional source of energy without the transportation problems and the combustion effects of fossil fuels. In prime areas geothermal energy is used for space heat, industrial processing, and the production of electricity. At all commercial sites the energy produces heat and/or electricity at prices that are less than any new capacity using fossil or nuclear fuels.

The critical immediate problem facing the international community is the use of energy located where it is needed, avoiding long transportation paths (needing to be politically and militarily protected), and avoiding the recognized hazards of increased combustion and nuclear wastes.

Government energy policy should be faithful to the long-range view that man can create and develop energy systems to use the abundant ubiquitous heat of the Earth that is being constantly generated. The elegant simplicity of developing man-improved geothermal reservoirs that will produce useful heat at prices that will not exceed the true cost of using fossil fuels moved around the globe will stand up to consequential analysis.

The economics of fuel supply systems (exploration, development, production, and distribution) are driven by the price and location of oil. World reserves are concentrated in regions having significant potential for supply disruption. Rising dependance on oil imports increases the risk of an economically damaging shortfall. The skilled labor force necessary to produce the amount of oil we presently need is no longer indigenous.

Increasing dependence on foreign sources of energy leads to a reduction in the flexibility of planning a foreign policy we can implement. As our energy sources become international, our military obligation increases to protect the sources.

INTRODUCTION

Geothermal reserves are developed where the accumulation of the earth's natural heat is near enough to the earth's surface to be economically recovered. In a broad regional sense, high-quality resources occur near and aligned with the earth's spreading centers (Iceland) or subduction zones (US, Latin America, Philippines, and the Japanese Islands). Electricity generated using geothermal heat is the least expensive available compared to that generated by any fossil-fuel plant meeting today's environmental standards for new plants.

Direct use of this energy for manufacturing processes and space heat is growing internationally because it is clean, indigenous, economical, and requires low capital investment. In the United States direct use of geothermal energy for heating and manufacturing is saving, in imported fuel-oil cost, equivalent more

than $167 000 000 per year. Growth in the direct use of geothermal heat has averaged 8% since 1970. Twenty-two district heating projects are in the engineering and construction phase. It is expected that these will save an additional ten million barrels of fuel oil annually upon their completion. Internationally, very large district heating projects are in operation in China, Hungary, France, Iceland, and Russia. The total capacity of foreign projects now in operation is estimated to reduce the consumption of heating oil by fifty to sixty million barrels per year.

Prediction of reservoir performance and compatibility of use are the principle concerns that impact the planning for increased use of geothermal heat.

BASICS

Finding geothermal anomalies is simple. Exploration requires geological and geophysical data. Regional geologic studies of structural stress features easily identified by surface geologic data or subsurface characteristics discovered by shallow-well drilling determine the area for concentrated evaluation of the potential reservoir. Localizing the area of high-intensity heat and producible reservoir requires sophisticated geology and engineering techniques. Utilizing equipment adapted from oil-field exploration and development has accelerated our success in putting this energy to work.

The reservoir fluids in hydrothermal geothermal fields are combinations of steam and hot liquids. In steam-dominated fields the produced fluids are primarily steam and noncondensible gases. In liquid-dominated fields the produced fluid is water with dissolved minerals and small amounts of dissolved gases. It is believed that the vapor-dominated field originates in the mature stage of liquid-dominated fields.

The type of produced fluids affect the design of the power plant and the environmental equipment needed to process the fluids after the heat has been extracted.

Reservoirs can be economically developed down to about 10 000 feet. The heat to be recovered exists in the rock framework. Fluids occupying the intrarock openings is heated by conduction. Heated fluids move through the subsurface by convection. To exist as a reservoir the hot rocks must have interconnected porosity. Such permeable rocks will have interstitial porosity, or fracture porosity, or a combination of these to yield effective, economic reservoirs.

ENVIRONMENTAL EFFECTS

The environmental impact of geothermal production can be reduced well below the most stringent requirements. Early development of geothermal energy in California coincided with the public's awareness of the great effect combustion-fired power-plants were having on air and water and the visual effect of very large power plant developments using high air-dispersal methods to mitigate the by-products of combustion. Natural dry steam carries ammonia, hydrogen sulfide, carbon dioxide, and boric acids. Natural surface emissions of these compounds pin point areas warranting evaluation.

Off-the-shelf equipment manufactured for industrial applications, such as the Stretford systems and crystallizers, are used to handle the low-level by-products produced with the geothermal energy. Products removed during the processing of the fluids carrying the energy may be be sold or disposed in approved dump sites. Under favorable conditions the cooled produced fluids may be injected into the subsurface

below the fresh-water aquifers. The compounds in solution with the geothermal waters may remain in solution after the heat has been removed. These can be returned to the subsurface where they originated.

Geothermal fields have very long life. Unlike open pit or strip mines, the local effect of producing and converting the energy remains fixed in location so that the area of impact is restricted. Geothermal fields may produce several decades before reclamation of the producing sites must be undertaken. Land used for geothermal developments during production is amenable for the uses it enjoyed prior to geothermal development. Several producing wells or injection wells can be clustered on as little as one to two surface acres. Geothermal plants normally are ten to one hundred megawatts in size and require two to five surface acres.

PLANTS

Geothermal plants operate on steam, flashed steam from liquids, or from a low boiling-point secondary fluid that is heated by the produced geothermal liquid in a closed system. An advantage geothermal plants enjoy over coal and nuclear plants is their small size. These small modular plants are simple to permit, and can be built in one to two years. Power can be added to a grid in small reliable units. Remote centralized control is very cost effective. Routine maintenance or unscheduled outages removes a small part of a system's deliverable energy. Capital investment of $1 500 to $1 900 per kilowatt delivered to the distribution system is less than for any other plant and fuel system that can be built today in this environmental climate.

ECONOMICS

Predictable economics depend upon complete costs of development and the probable cost of other available fuels for the region. System operating costs depend on the number of producing and injection wells required to service the plant. The number of wells needed is directly related to the temperature and chemistry of the produced geothermal fluids. The cost of the wells depend upon depth, diameter, inclination from vertical, type of casing, subsurface temperature, pressure, and type of rocks to be drilled. These costs can be established in a province that has extensive geothermal development.

Plants are engineered for the quality of the resource being developed. The type of plant and it's use determines it's cost. Direct-use plants are an integral part of the well supply system and the processing facilities. If the plant is to generate electricity, the cost depends upon the type and temperature of the fluid supplying the energy and the local environmental requirements. The type of plant effluent establishes the costs of building and operating the injection facilities.

The capital cost of the supply system and the plant can be optimized by considering the two working as a unit. The more a plant's efficiency is increased, the more it will cost to build, but the less it will pay for energy to operate at capacity. Wells can usually produce more energy if higher-temperature depths are reached, and if the wells have long completion intervals and large diameter bores that can flow at capacity. Such wells are more expensive to drill. An increase in the number of wells allows a less efficient plant to be used. Wells that must be pumped to produce required volumes of water are marginally economic at today's price of energy. These will have high maintenance and operational expense.

A summary of these costs for a typical development in the Imperial Valley of California after initial exploration and evaluation has been completed:

6 000' to 8 000' RESERVOIR

DEVELOPMENT WELLS	@	$800 000 - $1 000 000
INJECTION WELLS	@	$850 000
BRINE LINES	(8.5MM LBS/HR)	$2 800 000
IDC & MISC.		$9 000 000
POWER PLANT	(50MW to 70MW)	$95 000 000

The capacity of the plant varies as the ambient temperature changes between winter and summer affect the cooling capacity.

The price the geothermal installation receives for the electricity generated is critical to its economic viability. Price for the product sets limits upon how many dollars can be invested in drilling, construction, and operation. Oil-equivalent geothermal production is a parameter that can be used to develop an expected price for the producer. Oil-equivalent units can be stated as:

- equivalent in dollars produced,
- equivalent in units of heat produced, or
- equivalent in generating capacity.

The geo-energy can be priced as kilowatts at the plant's bus bar, pounds of steam delivered to the turbine, a percentage of the plants revenue, or avoided costs a user of another form of available energy would pay for that energy.

ADVANTAGES

Social advantages of geothermal energy include: space heating of large population centers with no combustion pollution, (low heat processing has the same advantage); an indigenous supply of energy that reduces the need for imported fuels; reduction of fuel-transport and production accidents; development and employment of local skilled labor; increase of local, state, and national tax revenues.

Political and military security advantages include: regional electricity supply can be effected with dispersed plants, unlike gigawatt fossil-fuel and nuclear plants; hardened sites can be achieved as fuel source and plant form a local unit; there is less political and military risk of maintaining long fuel-supply lines; Pacific Rim countries can reduce internal need for transportable fuels, improving the amount available for export in exchange for needed capital or products; the energy is generated by natural on-going processes.

SOCIAL AND TECHNICAL RESEARCH

The international impact on developing geothermal resources will be increased as research programs encouraged by our Department of Energy in cooperation with the international energy industry increase in scope. The cooperative science and technology exchange, as being practised within the European Economic

Community combined with the DOE work with the Latin American countries, will hasten the widespread acceptance of this important additional source of energy.

Research focused on basic rock physics and chemistry for extending the recovery of petroleum and natural gas is important to geothermal development. The understanding of rock and fluid reactions at elevated temperatures is an important factor in understanding geothermal energy accumulations as well as understanding the formation of and accumulation of oil and gas. To assess the producibility of geothermal or petroleum reservoirs we must be able to more effectively measure and map the distribution of permeability in potential reservoir rocks. Economically creating and enhancing incipient permeability in hot reservoirs would greatly expand the usefulness of the many areas with abundant heat that have not been developed because the rocks do not have sufficient permeability. The ability to enhance effective fracture permeability in warm high-pour-point lacustrine-oil accumulations would expand our known useful reserves of oil and gas. This ability would increase the regional use of geothermal energy.

DOE has been a leader in demonstrating the creation of effective geothermal reservoirs by mechanical means. This research has not been funded consistently so that long-term flowing tests can be conducted to obtain basic information that would be beneficial to geothermal developments, oil and gas low-permeability research, and hazardous-waste-disposal research.

The European and Japanese energy research programs are building on the past decade of US hot-dry-rock research. This is reminiscent of our experience in microchip, VCR, television, computers, and automated assembly-line inventions. The US does the initial basic research but stops short of the recognition of commercial use. The economic benefits pass to our competitor nations. They sell it back to us.

Cooperation in power-plant development to increase the efficiency of generating electricity between US design and Japanese manufacturing has resulted in a 33% increase in efficiency in the use of geothermal steam in the Geysers area of California. Thus fewer wells must be drilled and operated. The reduction in costs results in the Geysers producing electricity at a cost well below the 70 mils of California's newest nuclear plant, PG&E's Diablo Canyon.

Corrosion research begun by the US Bureau of Mines should be accelerated to develop tubular goods and power-plant turbines that can withstand the highly corrosive fluids that are found at elevated temperatures in deep geothermal and oil and gas reservoirs. This year power plants in the Imperial Valley of California have begun reliable commercial production using material and equipment that was conceived by research engineers using federal funding. The follow-on by private companies developed the commercial use of the hot supersaline brines that were useless until this cooperative research involving well completion and power-plant design was completed. Research should continue in materials corrosion, scale build up, and erosion.

The International Geothermal Association has been formed to encourage technology transfer, education, and research in the use of geothermal resources. Members from every geothermal-producing country in the world provide an opportunity to exchange germane information on a regular basis.

Research is vitally needed in understanding the mechanics of heat transfer from the rock framework to its contained fluids. This would aid the understanding of the time required to transfer a discrete unit of energy either from the rock or to the rock framework. This would be useful for reservoir performance predictions to evaluate potential oil and gas reservoirs and geothermal fields.

The goals for industry and government cooperative research should be to develop acceptance of this as an actual dependable source of indigenous energy of strategic importance. If the economics of these projects can be made predictable, the financial community will increase its support for large international developments.

OBSERVATIONS ON ENERGY USAGES IN DEVELOPING COUNTRIES: OPPORTUNITIES AND PROBLEMS

by

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INTRODUCTION

Fifteen years of working on energy and development problems in developing countries, including New Mexico as a developing country, have led to some observations that may prove useful to the Conference. In proposing global solutions, it is necessary for proposers to understand the limitations imposed due to the masses of LDC poor. Imagine for example that an expatriate came to any of us and proposed that we put 3/4 of our savings into some new artifact that the expatriate told us would significantly improve the quality of our life. Furthermore, we and our families have to work nearly continuously to provide the necessities of life and have little marginal time available. When the expatriate proposes a system for using the artifact that would absorb, we guess, 3 hours a day with a promise of saving us 5 hours a day of work sometime in the future, would we agree? Even if the expatriate provided the capital, would we be willing to make the commitment and put in the 3 hours per day? Suppose, further, that the artifact and system are completely alien to our culture and experience, would we listen politely?

The Conference has general agreement that the greenhouse and other environmental problems require immediate attention and significant changes to minimize or eliminate the threats of serious degradation of quality of life worldwide. The Conference proposes that developed countries limit or reduce their CO_2emissions to permit developing countries to produce more CO_2as they proceed with their own development. Some boundary conditions with which we must work are as follows:

1. The average US and other developed countries' consumers produce CO_2 directly and indirectly probably over ten times per capita the amount produced by poor people in developing countries. For scientists and engineers such as ourselves, the ratio may be 15 to 20 times.
2. LDC debt is horrendous and no recognizable solutions are in sight.
3. The average cash savings of poor people in LDCs approaches zero.
4. The average cash income of millions of poor people in developing countries is under $500 per year.
5. The population together with the increasing consumption desires in LDCs exceeds their food and economic carrying capacity.
6. Since developed countries are generally unwilling to forgive any significant amount of the LDC debts, the LDCs haven't significant cash reserves, and their poor have virtually no reserves. It appears that capital for development for the world's poorest regions also is miniscule. Thus solutions proposed need to be based upon this reality.
7. There is an upper limit to the nonrenewable energy production upon our planet that provides another limit to growth that has to be considered. It appears that unacceptable climate and geographic changes would result if we produce nonrenewable energy globally exceeding about 3% of the solar energy

received by our planet. At some past or proposed energy growth rates, this limit could be reached in less than 100 years!

DEVELOPMENT FROM A LOW CAPITAL BASE

My own experience in establishing a worldwide program in renewable energy development for developing countries has led to some of the following observations.

Many microsolutions, requiring multi-disciplinary innovations are required. Consider, for example, the geographic challenges posed by village people in Mongolia, Pacific Islands, Sahelian nomads, Bolivian Altiplano Aymaras, and northern New Mexico Mora villages. It is apparent that there are precious few affordable identical artifacts that can be manufactured in large numbers and distributed one way or another that would make significant improvements in the quality of life of these people and that there is no silver bullet that can be applied to stop, much less reverse, the deforestation taking place in developing countries.

My two decades of experience in industry, as well as the LDC work, has led me to identify six more-or-less independent functions, all of which must be met satisfactorily for any new technological innovation to be successful in the sense that it not only continues to be used but is adopted by others.

The six functions are:

1. engineering/science of the artifact (the hardware, software, system aspects),
2. manufacturing (replicating),
3. financing,
4. marketing,
5. legal (including environmental, religious, cultural, and other factors), and
6. management.

Upon careful examination, it is clear that continued developments in each of the six functions are necessary in each geographical region of our planet. Fortunately, we can share learning from the experiences of others. Further, it is clear that what is appropriate in one place may not be in another.

Clearly, confidence building requires broader sharing than in number 1 above, the engineering and science of artifacts/systems. Often, we find that impediments are among the other five.

When a technical innovation is successful in the United States, it generally results in a successful business. Thus we have developed significant experience and understanding of the entrepreneurial process. In developing countries, the entrepreneurial process works well at the village market level and in microenterprises, often in the informal sector throughout developing countries.

A result of a completely novel innovation that meets felt needs and for which capital requirements are available is that "contagion" takes place. Without outside pressure, as in technology push, people widely emulate the innovation, and it spreads based upon local resources. Thus, seeking solutions that are likely to prove contagious is a major challenge to our development effort to reverse the environmental degradation and greenhouse problems.

As Ann Ehrlich pointed out, we have often learned that, in tropical areas, the traditional technologies permitted higher sustainable population densities than approaches we have fostered. It is essential for us to have a broad prospective and an open, learning attitude.

As we consider the components of innovation, it seems essential to point out a central element that contributes significantly to the success of capitalism: a reward system that encourages brokerage that is independent and not centrally controlled. By brokerage is meant putting together a potential supply with a potential user. As we think about the significance of brokerage, we recognize the value of brokerage within large organizations, whether corporations, national labs, or others. Developments and knowledge in one component of the system are often not known about in other components that could use that information, or gain from the knowledge. Often, informal brokerage contributes significantly to bridging the gap. A major challenge now in the United States and in the Soviet Union is "technology transfer." By this, we commonly mean the use of developments in the military and weapons programs for commercial, consumer, or industrial applications. Effective brokerage is a major challenge.

Where contagion takes place, as in the Lorena stove in the Guatemalan Highlands and more efficient charcoal stoves in Kenya and Sudan, we have some useful models to examine. However, accurate examination of models is essential. For example, some, believing that the Lorena-stove itself was an immutable solution, sought to transfer the Lorena stove technology to warm areas in West Africa, and the transfer failed; in West Africa the people didn't need the heat from the stove to warm their rooms.

Since Daniel Webster, who was excited by the power of the newly developing mechanical technologies and who received large subsides from the railroads, there has been a significant transfer of religious faith to the engineering/science technological fix as deity. This has been sustained by the faith that problems can always be solved by technology. We, in this audience, are more likely to believe in the scientific method. We recognize that an identifiable problem will not necessarily yield to a technological solution. However, we keep at it, seeking to approach the solution as closely and is practically as possible.

As an example of a challenging problem, consider Egypt, a country that has about 40 000 villages of more or less 200 people. In 1979 the American University in Cairo held a desert conference inviting engineers, scientists, sociologists, and others to examine ways that the enormous amount of currently unused desert land might be made productive to support the exploding population along the Nile. For some time, Egypt has been unable to produce sufficient food for its own population. Further, since the construction of the Aswan Dam, a number of secondary problems have emerged due to the loss of the annual flooding and the comparative drop in topsoil thickness. At the conclusion of the conference, in which I contributed a paper with some technical information about renewable energy technologies, it was painfully evident that the engineers and scientists did not see a way to support much of a population in the desert area; sociologists would need to develop means for halting and preferably reducing the population explosion. However, the sociologists pointed out that there is no way that they could perceive that the population growth could be slowed significantly and the engineers and scientists would have to solve the food and economy problems. I thought of the metaphor of a vehicle going down a long hill with failed brakes.

Another time, doing a consultancy in Egypt regarding kerosene cookers, I observed the following. There are about twenty million kerosene cookers in Egypt. Traditionally, a bride receives a kerosene cooker upon marriage and uses it throughout her lifetime. Although there is an infrastructure repair system available, many stoves are not used efficiently. However, the distribution system itself has significant problems. Fuel is subsidized so that it is comparatively inexpensive and widely available. The distribution system itself is leaky. Furthermore, there were warehouses of stoves that the central planners had required to be built that consumers didn't want and didn't buy. There was a significant difference in the ineffectiveness of their centrally planned system, which appeared to have no effective brokerage system, and the effectiveness of the private system, which produced stoves that people wanted. My overall conclusion was that the major

problems were in the system itself, that changes in stove design would have comparatively negligible impact upon kerosene consumption in Egypt.

While viewing pyramids in Egypt, I evolved a mental picture of our LDC development challenge. Imagine a pyramid which has a solid base up to, say, 10 to 20% of the height. Atop this base is a narrow riser going to the top 5% of the pyramid, leaving the bulk of the pyramid to be filled in. The top portion of the pyramid, being comparatively unstable, is supported by sky hooks of foreign aid. Too often we find that a commercial elite and worse, politically supported corrupt people sustain a developed country life-style. They compose the sky-hook-supported top of the pyramid and, too often, place their savings and investments in developed countries. In a simplified sense, the top-down strategy involves seeking to fill in the pyramid from the top. The bottom-up strategy seeks to build the pyramid up from the bottom.

Although worldwide, village-market-level microenterprises function efficiently, there seems to be difficulty developing the next level of business. One possible explanation relates to the necessity of expanding education in LDCs. Intense national competition, and difficult undergraduate programs, provide effective systems for filtering out the academically brightest. Many of these people go to developed countries for masters and doctoral degrees. Too often, their graduate work focuses on matters of importance in the developed rather than in the developing countries. Then a sizable percentage of the graduates find ways to stay in the developed countries. Those who return frequently find substantial frustration working in national laboratories (where the ratio of PhDs to technicians may be the reverse of what it ought to be for an effective laboratory) and find, as in universities, that acquiring instrumentation and equipment is a long and tedious, often not successful, process. These bright people tend to have been educated away from the local market-level skills and are prepared to work in large corporations or for the government. Since there are few large corporations, a substantial percentage work for the governments and others in universities. Though a considerable intellectual resource, they contribute directly to the overhead cost and the deficits rather than directly to wealth production.

Bottom up developments have their problems too. For example, Howard Geller reported upon his effort to develop more efficient stoves in India. After clearly demonstrating the superiority of simple changes in designs of these chulas, Howard was startled to find that his own driver hadn't bothered to acquire the more efficient chula. The driver responded, "why should I bother?" It was his wife's work to gather fuel for the chula. It didn't seem to matter to him to save significantly the fuel-gathering effort of his wife.

In thinking about what can lead to contagion and what leads one to make a choice between one or another technological approach, I have defined a qualitative measure of comparative appropriateness. Incidentally, within this definition the term "appropriate technology" should be applied only as a comparison between alternatives, not as an absolute. Clearly, what is appropriate in central Manhattan is different from what is appropriate in the Masi Mara. I define a qualitative entropy function having four components:

1. the well known thermodynamic effects,
2. materials (especially irreplaceable),
3. money, and
4. labor of different quality.

Note that each of these four, when spent, becomes unavailable and the qualitative entropy function rises. We all, more or less, learn this qualitative entropy function intuitively as we grow up. For rational decisions, we tend to use it for comparisons. However, our decisions, of course, are also embedded in the dos and don'ts of our cultural traditions, as well as our emotions.

In examining proposed solutions dealing with the greenhouse and environmental problems in ways that contribute to confidence building, I believe it is essential to consider filling the brokerage role and to recognize the complexity of the multitude of microsolutions that are possible.

I mentioned New Mexico as being like a less developed country. The average per-capita income in New Mexico is 46th out of the 50 states. There are several expatriate firms, including Los Alamos National Laboratory, Sandia National Laboratories, etc., that receive income from, and are directed by, forces outside of the state, and the bulk of the results are used outside of the state. There are three cultures: anglo, hispanic, and three American Indian tribes. Surprisingly, New Mexico also has had the second highest percentage of people with doctor's degrees in the United States. Some of the impediments I've observed to growth of entrepreneurial business in New Mexico are as follows:

1. Because of geography, entrepreneurs can rarely be within one hour's travel time of being embedded with significant samples of their customer base.
2. New Mexico does not have enough people with entrepreneurial attitudes or skills.
3. There are significant government impediments.
4. New Mexico has insufficient finance possibilities, especially for small companies that have small-to-moderate potential growth rates.
5. The support infrastructure of services, management, consulting, print shops, machine shops, etc., is developing but is not yet at the level of major entrepreneurial centers.

In spite of the above, one of the poorest counties of New Mexico had one of the highest densities of solar homes of any county in the state, probably in the US, due in large part to the effectiveness of the voluntary (PVO) New Mexico Solar Energy Association. This organization provided a forum for mutual learning and the brokerage function.

Finally, since this Conference is a joint US/Soviet effort, it seems appropriate to close with some words about Dostoevsky written by David Magarshack ("The Best Short Stories of Dostoevsky," the Modern Library, New York). "The short story *The Dream* gives us Dostoevsky's final judgment on man. And negative though this judgment is on the whole, Dostoevsky never despaired of man. Division of the golden age may be a dream, but it is a dream that makes life worthwhile even if it can never be realized; indeed it makes life worthwhile just because it can never be realized. In this paradox Dostoevsky the creative artist seemed to glimpse some meaning in man's tragic story. But he did not stop there. He was appalled by the arrogance of the intellect, and in *The Dream*, he again stresses the fact that reason without feeling, mind without heart, is evil, is a dark cellar; for reason bears within itself the seeds of destruction. Only through pity, love and mercy can man be saved. This message, as Dostoevsky himself put it in *The Dream*, is an "old truth;" but like the hero in *The Dream*, he went on preaching it all his life."

For those, who like myself, seek rational solutions, this is a sober thought indeed.

POLITICS OF INTERNATIONAL ENVIRONMENTAL COOPERATION

by

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INTRODUCTION

As is widely known, transboundary pollution problems require international cooperation for their solution. Yet, countries are commonly averse to cooperate seriously due to doubts about reciprocity, verification, and the common political antipathies that impede interstate cooperation.

How then is cooperation to occur? Recently, in the environmental sphere it appears that there has been an emergent new form and process of cooperation, driven not by state power but by the collective beliefs of groups of technical specialists. In this presentation I will seek to sketch out the dimensions of this incipient mode of environmental cooperation and indicate its boundaries and preconditions, based upon international efforts to protect the Mediterranean Sea and the stratospheric ozone layers from pollution. Lastly, I will draw up a checklist for its application elsewhere.

INTERNATIONAL ENVIRONMENTAL COOPERATION

There has been a striking amount of successful environmental cooperation in the past decades—in terms of statements or commitments (the signing of international treaties), and in terms of actual deeds (policy making and investments), as well as in terms of actual outputs (environmental quality). The United Nations Environment Programme (UNEP) indicates that of a total of 112 multilateral environmental treaties that had been concluded by 1983, over two-thirds were signed from 1970 to 1983.[1]

Moreover, public statements by high-ranking government officials demonstrate a growing "environmental consciousness,"[2] as has the spread of national expenditures and legislation in support of such efforts.[3]

Environmental quality has even improved in advanced industrial societies that have undertaken such efforts, although environmental problems seem to be becoming more acute in industrializing LDCs and coastal pollution from land-based pollutants remains a threat.[4]

Since its establishment in 1973, UNEP was responsible for 43% of the treaties concluded until 1983. UNEP officials were prominent actors in their negotiation. The Regional Seas Programme, under the leadership of Stjepan Keckes, was responsible for 23 treaties between 1975 and 1983 covering ten regional seas.[5] Executive-Director Mostapha Tolba played a major role in the conclusion of the 1987 Montreal Ozone Protocol and the 1989 Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal.

Recent efforts under UNEP's guidance demonstrate substantial shifts in the substance of international environmental treaty making. First, there has been a shift to dealing with land-based sources of pollution and atmospheric pollution away from prior efforts involving the relatively easier and less costly problems

of marine dumping and oil pollution. Environmental diplomacy has become more comprehensive, covering more pollutants and more sources of pollution than previously. A number of environmental treaties have also been adopted that were based on ecosystemic logics rather than political borders, such as regional seas, river basins, and airsheds. Before UNEP's involvement, such treaty making had been limited to fisheries. In addition, the 1989 signing of the Basel Convention indicated the international community's readiness to address, for the first time, the economic channels by which pollutants are transmitted, in addition to the traditional manner of managing the physical channels, or environmental media, through which pollutants are transmitted.

Thus, in the aggregate, viewed over time, the evolution of environmental problem solving may be construed as a process of learning. International decision makers have gradually come to accept a broader, interdependent, symbiotic, and holistic conception of the environmental system for their pollution control efforts and have adapted their policies accordingly. Still, most arrangements remain remedial rather than preventative—coordinating policies to regulate emissions, rather than addressing the conditions that give rise to their creation.

Although many of these advances in environmental cooperation were achieved under UNEP's guidance, UNEP's activities are part of a broader transnational effort. It is true that to some extent such cooperation is instigated and fertilized by an international organization, but it must be realized that the organization's effectiveness arises from the broader set of forces, of which it itself is a part.

Unlike most instances of international cooperation, these treaties were not concluded as a result of a dominant state party, usually the United States, taking a leadership role. This is particularly hopeful, given the putative decline of US leadership on the global front, so that cooperation without such hegemonic support may be possible.

ECOLOGICAL EPISTEMIC COMMUNITIES AND ENVIRONMENTAL COOPERATION

In general, international cooperation has been led by a powerful actor. Yet, under recent conditions of uncertainty, specialists play a significant role in attenuating such uncertainty.[6] Commonly in such environmental cases, leaders have been uncertain about the extent of pollution, the interaction between specific pollutants, the costs of clean up, and the likely actions of their neighbors. Such conditions are particularly puzzling in technical issues that pose low probability but high-risk outcomes. Traditional search procedures and policy-making heuristics are impossible, and state interests may be hazy.

In such circumstances, information is at a premium, and leaders may be expected to look for those able to provide authoritative advice to attenuate such uncertainty, and either consult them for policy advice and/or delegate responsibility to them. Subsequent discussions and policy debates will then be informed and bounded by the advice that leaders receive. International negotiations may then be viewed "as a process for reducing uncertainty,"[7] as well as a process of deferring to specialists regarded as possessing a reputation for expertise in the domain of concern.

Traditionally, states have been impervious to technical advice, which was usually subordinated to shorter-term political concerns. Studies found that experts tended to be co-opted or defused by able politicians. Yet, if the group of specialists share a common world view, or set of cause-and-effect relations, they are likely to be particularly influential because they will resist the political temptations to subordinate their advice to existing political concerns. When introduced to decision making, their advice will reflect

the community's shared causal beliefs about what specific substances to control and how and will reflect its belief in common ends or values to which the policy should be directed.

Such a group of specialists with shared cause-and-effect beliefs constitutes an "epistemic community." Thus an epistemic community could prove influential in defining the dimensions of a problem and would consequently be privileged in identifying likely solutions. In short, an epistemic community could contribute to identifying problems, defining specific policies for collective adoption, setting agendas, bounding discussions, designing programs, enforcing policies, and even helping to identify state interests.

Embedded in international organizations, such as UNEP, they may help set agendas, bound discussions, present issues for collective treatment, and propose solutions. Embedded in national administrations they may facilitate agreement at international negotiations, as well as guide their country's foreign policy in ways consistent with their own technical understanding and preferences.

In the case of environmental issues, this epistemic community has been comprised of ecologists. Ecologists often come from diverse and hybrid disciplinary backgrounds but share a common belief in the need for holistic analysis that is sensitive to the possible feedback and synergistic relationships between a variety of possible variables.[8] Despite uncertainty about the volume and dispersion of pollutants in the ocean, for instance, they do share a consensus about the relationship between inputs of contaminants and effects on the ecosystem. They share a belief in common ends of directing governments to protect the environment as well as in self-reliant development. Ecology has been described as a framework that assimilates other scientific disciplines:

> This new science, which is an integration of the traditional disciplines of geology, oceanography, ecology, meteorology, chemistry, and other sciences, has a variety of names... Its subject is nothing less than the composition, behavior and interactions of the planet's nonliving realms or phases—the atmosphere, geosphere, and hydrosphere—and its living realm, the biosphere, which encompasses parts of each of the others.[9]

ECOLOGICAL EPISTEMIC COMMUNITIES AND COOPERATION IN THE MEDITERRANEAN TO PROTECT THE OZONE LAYER

In fact, such experts appear to have played a widespread role in international environmental negotiations. As a consequence of stressing the linkages between ecosystems, they encouraged governments to control a broad assortment of pollutants, as well as to redesign development-makingprocesses to integrate environmental considerations into more traditional policy making.

UNEP, with its "catalytic" mission, has generally been the lead international environmental agency. Staffed at the upper levels with ecologists, UNEP has consistently pressed for strong, enforceable, and comprehensive treaties that are sensitive to ecosystemic dynamics and national development ambitions. Its two executive directors, Maurice Strong (1972–1975) and Mostapha Tolba (1976-present) publicized the environment, sought to serve as a public environmental conscience, as well as to bully or cajole delegates and heads of state to adopt broader forms of environmental protection. This process is most clearly seen in efforts to protect the Mediterranean from pollution and to counteract the depletion of stratospheric ozone.

An ecological epistemic community greatly facilitated cooperation in efforts to control Mediterranean pollution. The Mediterranean Action Plan (Med Plan) consists of a set of regional arrangements to control

multiple sources of pollution, monitor the quality of the environment, and to design alternative development patterns that are less environmentally threatening. Developed under UNEP's auspices, all 18 littoral countries now participate. Governments were initially loathe to cooperate, due to the high level of political animosity and suspicion between the LDCs of the Southern shore and the DCs of the North, as well as a poor understanding of the extent, causes, or costs of pollution in the Mediterranean. Yet, confronted with public alarm about the possible "death" of the Mediterranean, governments authorized UNEP to assess the extent of pollution and to draft a treaty for its control.

An ecological epistemic community permeated Mediterranean decision making. The UNEP Secretariat coordinated meetings and produced background documents and proposals. UNEP also established a transnational alliance with like-minded regional marine scientists. Some scientists shared UNEP's broad vision, others were limited to more parochial concerns with specific pollutants, but all were united within UNEP's comprehensive approach, which integrated narrower concerns as well as promising research funding and a sense of community for researchers who felt they were poorly supported at home. When these marine scientists came to staff national Environmental Ministries, as they were established throughout the region during the 1970s, they informed their governments of the need to control more sources of pollution and advised their governments to support the Med Plan, to ratify its protocols, and to develop national pollution control policies and legislation consistent with it.

Thus, under the guidance and drafting of the ecological community, the Med Plan came to reflect the holistic bias of its drafters.[10] The Med Plan included an integrated planning component. Countries were encouraged to develop their own facilities for environmental monitoring, with UNEP financing, rather than pursuing the cheaper and more efficient but less politically effective technique of contracting out environmental monitoring. At the national level, once they were entrenched within their domestic environmental ministries, members of the epistemic community pressed their governments to take more constructive stances at international meetings, to support a stronger Med Plan, and to enforce environmental regulations. After such officials became entrenched, national policies, organizations, legislation, and budgets all became more environmental. Countries without such intervention showed no change.[11] Elsewhere, UNEP has encouraged the development of environmental monitoring based on a holistic logic of the interrelatedness of ecosystems, and, hence, the design of monitoring programs to identify the multiple interlinking of the substances being monitored. Ultimately, governments would be asked to control such materials. The final form of the Med Plan was much more comprehensive in scope than any of the countries initially anticipated

In the negotiation and implementation of the 1987 Montreal Ozone Protocol, a similar group of ecologically minded atmospheric scientists played a comparable role. The epistemic community channelled discussions toward a strong treaty by disseminating information that suggested the need for strong international CFC controls. It also prevailed over rivals in decision making within the United States government and the private sector, so that the United States pressured countries to adopt a stronger treaty than was initially anticipated. Through UNEP and the US government, the epistemic community kept the issue salient on the international agenda to maintain ongoing negotiations and exercised political leverage through the US delegation to compel other delegations to accept a strong treaty. As scientists with similar causal beliefs acquired access to their governments throughout Europe, most recently in the UK, these countries in turn came to adopt domestic policies to implement the Protocol, to call for an accelerated pace of implementation of the treaty, as well as an immediate redrafting to make it stronger in light of recent findings that stratospheric ozone is being depleted more rapidly than anticipated.

Without the presence of the epistemic community in either of these cases, it is likely that there would have been less cooperation, that its form would have been less comprehensive (i.e., fewer pollutants covered,

less sensitivity to related issues), and that its enforcement would have been slower and less aggressive. It seems to have played a similar role as well in other international maritime discussions as regularized negotiations establish regular channels of interaction among the relevant "technical elites" in participating countries, NGOs, and international organizations.[12]

Still, we must remain cautious about the generalizability of such processes. They are likely to remain issue-specific and not promote political or other forms of integration, and they are subject to reversals. The extent of inhibiting pressures against an epistemic community and the interplay between state power, social interests, and epistemic knowledge is not yet well understood.

COOPERATION AND CONFIDENCE BUILDING

Although the epistemic community of ecologists may well give rise to international environmental cooperation, it is less clear that all epistemic communities will give rise to cooperative outcomes or that such cooperation will lead to greater confidence among governments. Whereas it is much easier to defend the need for policy coordination to manage transboundary pollution, policy coordination is much less clearly a "good thing" in such areas as international trade (or so the recent neo-mercantilists tell us) or North-South relations. Moreover, such groups of specialists may develop knowledge that demonstrates that everyone does not benefit from cooperation and hence, sharpen conflict of interest and an erosion of cooperation.[13]

Epistemic communities could give rise to confidence building by enhancing the quality of actors' expectations of others' behavior. By better understanding the process by which information is processed in a partner, another country may become more confident that its own actions will be reciprocated or that certain initiatives would be likely to persist in the future. Operating through international organizations with a capability for publicity, such as UNEP, members of an epistemic community could verify compliance with agreements. However, as argued in the previous paragraph, such efforts at cooperation could, under certain circumstances undermine confidence building by indicating that the assumptions of eventual joint gain are flawed.

Nor need common interests, or even greater transparency of interests *necessarily* lead to improved chances for cooperation. Recall Francis I's assessment of the difference of interests between Charles V and himself, which gave rise to constant warfare: "None whatever. We agree perfectly. We want control of Italy."[14]

CHECKLIST FOR CREATING AND MAINTAINING EPISTEMIC COMMUNITIES AND COROLLARIES

The proposition here has been that if epistemic communities exist—and can maintain fairly stable access to decision makers and keep rivals at bay—then international arrangements will be developed that will closely resemble the community's preferences. Based on these assumptions about information searching by governments and the common interests of members of an epistemic community, a number of particular hypotheses, corollaries, and techniques may be developed to improve such a process and to facilitate its application elsewhere. The key to such a process, as UNEP has recognized, is the concurrent development of political arrangements and technical environmental assessment.

1. Crises precipitate action. In principle, there may be an optimal frequency of crises that is sufficient to focus attention on the problem but not so frequent as to undermine the authority of those responsible for formulating policy. Crises must be of a sufficient size to generate attention, yet not so large as to be fully terminal.

2. Identify transnational epistemic communities organized into transnational networks.

3. Establish rough technical consensus within the community.

4. Create access to international and domestic authorities. Such institutions, such as UNEP or domestic environmental ministries, can serve the important role of providing financial support for ongoing research, paper writing, and maintaining contacts within the community, by conferences, telecommunications, etc. Once established within an administration, an epistemic community is likely to retain its influence until a new crisis or paradigmatic threat challenges its authority.

5. Provide scientific advice through domestic channels. This way is the most effective since technical advice from foreign scientists or international organizations is often highly suspect in LDCs.

6. Consolidate bureaucratic power at both the international and national level. International organizations are likely to be more effective for consciousness raising, circulating information, agenda setting, and for monitoring environmental quality and national compliance with international arrangements. National power consolidation is likely to be more influential for enforcement and for compelling other countries to comply with preexisting international arrangements.

7. Expand domestic support. Although environmental policy is usually elite-driven rather than popular, broader domestic support will reinforce the bureaucratic influence of an epistemic community within national administrations. Despite recent emergence of Green Parties throughout Europe, actual government policies for environmental protection and for international cooperation preceded such mass mobilizations of public opinion, which have still tended to concentrate on single issues.

Still, public commissions such as the World Commission on Environment and Development may publicize events, build up political support for international arrangements, circulate information, and elaborate domestic policies in compliance with such arrangements. International efforts may spawn new domestic groups, or their designers may take advantage of existing networks of NGOs to amplify their message.

8. Sequencing matters. Start with umbrella assertions of motherhood that are easier to conclude or build from existing international regimes. UNEP has followed a "slippery slope" strategy of committing states to broad arrangements with few commitments, and subsequently developing more effective and constricting protocols that would have been politically unrealistic at the outset. Domestic constituencies are in place for subsequent treaty making, and more information is probably available to bolster their positions. Agreement may be easier to reach when leaders need international validation or support for what they already wish to do domestically. An appeal to international standards may facilitate domestic application.

9. Not all environmental problems require standards and regulation. Some cases, such as those without sufficient understanding of the winners and losers in case of an environmental catastrophe, may be best managed through insurance funds, as have been designed by the IMO for oil spills. Such an arrangement may be most appropriate for global climate change, for which the most politically and socially tractable strategy may be to prepare for global warming through investments in drought-resistant

10. This process is reversible. If the knowledge base of the epistemic community collapses the epistemic community's reputation for a monopoly on uncertainty, reduction will be vulnerable. Such an erosion of authority is likely to be lagged slightly, however, as the publicization of the collapse of technical

consensus will take a while to percolate up to higher-level decision makers responsible for deferring to such groups. Still, as countercommunities emerge to challenge the causal beliefs of the epistemic community, the natural exchange of scientific ideas will gradually expand to the broader policy world and public. With more sophisticated science reporting, such a flow of information may be fairly rapid.

HOW MAY THIS BE GENERALIZED TO OTHER ISSUES?

This process may be appropriate for generating and understanding cooperation in other functional areas as well. In the sphere of the environment, regional and global environmental problems, such as acid rain and deforestation, may be resolved through the application of such a technique. Global warming is less clear, as the political and economic costs of international responses are much higher than in other issues and the degree of technical consensus is much lower. It may still be possible to generate more coordinative reactive and conservation measures through transnational epistemic networking.

Outside the environmental sphere, technical cooperation in economic matters may be possible in areas in which mobilized epistemic communities exist, for instance, international standard setting or development and technical-assistance activities.

It may also apply to bilateral arrangements. The recent climate of open environmental concern in the Soviet Union[15] could be particularly conducive to the involvement of such groups of specialists, should they exist, in the context of ongoing efforts to coordinate activities for space exploration and monitoring, atmospheric monitoring, nuclear accident prevention, and disaster relief.

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PROPOSAL TO ESTABLISH A UN ENVIRONMENTAL SECURITY COUNCIL AND GENERAL ASSEMBLY

by

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The following is a proposal formulated by the three authors at the Conference on Technology-Based Confidence Building.

Because no nation-state is in control of its environmental fate, we propose the following international institutional innovations to better manage the transnational dimensions of the new global environmental agenda. We propose the creation of a new United Nations environmental body as an adjunct of the existing Security Council.

The new body would be bicameral, consisting of:

1) A nation-state chamber that would have representatives from the five permanent members of the Security Council, plus Japan, the European Economic Community (after 1992), and other members on a rotating basis; and

2) A transnational chamber, consisting of representatives from nongovernmental organizations, including corporations, scientific unions, environmental associations, and other related bodies.

These two bodies would operate in parallel to the existing Security Council and General Assembly but would be concerned with international environmental questions. Both chambers would be supported by the UN Secretariat and represented in the Secretariat by a newly created Undersecretary General for Environment and Development. The UN Environmental Programme (UNEP) would remain responsible for environmental research and for coordinating the environmental activities of other UN agencies, with a larger budget that would allow it to fully pursue this mission.

There are precedents and analogies for the arrangement proposed here. The institutional structure is analogous to the EEC's efforts to represent many interests in Europe:

The European Council of Ministers is similar to the proposed Nation-State chamber;
The European Parliament is similar to the Transnational Chamber;
The European Commission is similar to the Secretariat; and
The advisory group is similar to the Senior Advisors group of the Commission on Transnational Corporations.

AN INTERNATIONAL AGENDA FOR ENHANCED NUCLEAR SAFETY AND PERFORMANCE

by

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INTRODUCTION

Nuclear power represents 17% of the world's electric energy generated in 1988, and this fraction will continue to grow for the remainder of this century. Today, 26 nations have made major commitments to the nuclear option and in 13 countries nuclear power is over one-third of their electric capacity. In France and in Belgium, nuclear power represents about 70% of their capacity.

The importance of this technology to the worldwide economy and environment is enormous and may grow more so in the future. The potential limitations to further development and deployment are not due to excessive costs, inadequate demand, alternative technologies, nor technological barriers to design improvement. The future limitations are most likely to be determined by the behavior of the owners and operators of our current plants.

Public confidence in nuclear power was shaken by the Three Mile Island accident, and the public beame outspoken after the Chernobyl event. It is my belief that another accident on a similar scale will be the death knell of nuclear power. I do not believe there would be an instantaneous shutdown of all plants, although there will be agitation for just that. What will happen is that a widespread conclusion will emerge that fission technology is too dangerous a technology and all further electric generation should come from nonnuclear sources.

It is easy to identify particular nations where public concern is most volatile. Sweden is operating today with a plan to phase out their nuclear plants. The industries in the Federal Republic of Germany and in the United States are at a standstill. Public concern and awareness is felt in many other nations.

We are in a situation where every single nuclear plant in the world holds every other plant as a hostage. The impact of another accident is not limited to local or national boundaries.

One hears a great deal about the promise of second-generation plants. The present favorite description is "inherently safe," implying that accidents cannot occur at such plants, or if they do occur, there will be no release of radioactivity. Such claims may or may not be true. They will be irrelevant unless the existing 450+ plants operate safely for their full lives.

Thus, the truly vital question about the nuclear future is how to enhance the safe operation of the capacity already on-line. It is this topic that is the focus of this brief talk.

THE PRESENT EFFORT

Concern with safety is hardly a new topic in the nuclear profession. Such matters have dominated design, licensing, and operations from the beginning. The industry and its regulators have cooperated in creating national and international vehicles to improve understanding of safety-related issues. Within

the past few months there was the creation of the World Association of Nuclear Operators (WANO), to demonstrate the worldwide commitment to safety. The WANO mission is quite explicit with regards to plans and priorities. These include the collection, analysis, and exchange of operational information as well as the sharing of lessons learned.

Other international vehicles have been created to assist in the exchange of information, knowledge, and experiences that relate to safety. The International Atomic Energy Agency (IAEA) was created in 1957 to provide a worldwide forum. A major IAEA activity is the "operational safety review" program, which involves expert teams visiting reactor sites to review and promote safety. The agency has many other programs and projects that contribute to nuclear safety.

The Nuclear Energy Agency (NEA) of the OECD has as its primary objective the promotion of co-operation between governments of participating countries in the development of nuclear power. Activities include the coordination of national regulatory policies and practices that impact safety, radiation and radioactive waste management, and liability and insurance. The agency also engages in developing exchanges of scientific and technical information. Further, the NEA facilitates the creation of international research and development programs.

On the domestic scene the two most important organizations are the utility-sponsored Institute of Nuclear Power Operations (INPO) and Electric Power Research Institute (EPRI). INPO was created after the TMI accident to coordinate industry-wide efforts at accident prevention and performance improvement. Major programs include evaluations of plants and plant owners, performance review and analysis, accreditation of personnel, and event analyses. INPO is also the coordinator and repository for information and databases used domestically and internationally. EPRI is the research arm of the U.S. industry. A major element of its nuclear programs relates to safety. Particular emphasis is upon the collection, analysis, and integration of maintenance experience.

All of the organizations mentioned above are important, competent, and necessary. However, I believe that there are further efforts that should be added to those already in place. In particular, I believe there are fundamental questions in the areas of management, policy analysis, and technology that require an international cooperative research effort.

THE INTERNATIONAL AGENDA

It is my belief that there exists a very close coupling between safe performance and good performance, i.e., high unit availability. If this belief is correct, then the objective of achieving safe performance brings with it the economic benefits of good performance. Investments in new knowledge that improves safety should also be seen as investments in high-capacity factors.

It is my view that there are three pathways to a serious accident, namely; external events such as earthquakes, failures of hardware such as at TMI, and human failures such as at Chernobyl. External events are dealt with by design, and the industry around the world has an excellent record of good, conservative design. In addition, licensing authorities exercise independent judgement on the adequacy of design and construction. It is in the areas of hardware and/or human failures that new research is needed.

Management Science

We are all aware of examples of well-run organizations as well as poorly-run organizations. Similarly, we are aware of very diverse performance records of various nuclear utilities. Finally, there are very great contrasts in performance between national nuclear programs. If there is a relationship between performance and safety, then an effort to improve safety must begin with a better understanding of the causes of the great variations in plant performance.

A useful beginning point is for scholars in the field of management science to try to identify the measures of human and organizational behavior that characterize excellent utilities and/or programs. Certain obvious measures are not adequate. For example, several studies have attempted to relate staff size to performance without any success. Other studies have shown that the wide variations in national performance are not explainable in terms of national contexts such as the structure of the utility industry or the structure of the supply industry. There are examples of good performance found in many contexts.

The intellectual challenge is to extract from the wealth of available information certain indicators whose presence or absence correlates with performance. And then to develop a theoretical model of how these indicators are representative of management practices or structures that promote excellence.

I do not underestimate the difficulty of this task, but I believe it is a central issue for the future. Not only in regard to nuclear plants but for the increasing number of technically complex and dangerous activities that characterize contemporary life.

Policy Analysis

Nuclear power plants are subject to the control and/or policies of many agents, e.g., safety regulators, economic regulators, environmental regulators, energy-policy regulators, manufacturer policies, vendor policies, corporate policies, and plant-specific policies. The most common complaint heard from plant managers today is that they have too many masters, all with conflicting agendas. I believe the managers' perceptions are correct, at least in the United States, and some clearer understanding of the impact of all of these overlapping pressures is needed. In particular, some structure should be created that would allow for the quantification/evaluation/comparison of the relationship between policies at various levels and the safe operation on the plant.

One example of a potentially serious policy issue is arising in the United States. Several state public utility commissions (PUC) are adopting incentive programs for utilities regarding plant operations. The basic idea is to reduce the risk to rate payers by encouraging a maximum performance from each plant. Typically rates allowed for energy are established such that performance in a certain range of capacity factor will provide adequate revenue. If performance falls below the minimum value, then stockholders will suffer a loss because the PUC will not allow adequate recovery of costs. Conversely, if the plant exceeds an upper bound, then the additional income is awarded to stockholders. As an economic incentive the policy makes sense. However, the policy is fraught with the potential for safety problems. It is all too easy to imagine plant managers feeling pressure to reach a certain capacity factor and postponing or ignoring needed safety-related services.

The research task to be undertaken in this study is to develop an understanding of the full range of policies that exist in the nuclear utility industry, to identify and examine the motives that underlie the policies, to determine the relevance of the policies to safety, and to create a means of relating policy alternatives.

Technology Development

For many years the role of service and maintenance has been seen as "low-technology" in the United States. The best and the brightest graduates of our technical institutions saw their future in research and high technology. Any potential employer who held out the promise of a position in the service/maintenance area remained just that—a potential employer. Little has happened to change this perception, and I believe this is tragic.

Real-life experience and O'Toole's Law confirm that hardware will fail. The possibility of designing fail-safe systems is intriguing, but it is not true of the existing plants, the very ones we need to operate for the next 20-40 years. However, the Japanese have demonstrated that an appropriate service/maintenance program can reduce the rate of occurrence of failures, albeit with considerable expense.

It seems obvious that a re-examination of the service/maintenance function is called for, with particular emphasis upon "predictive" maintenance. There have been enormous strides in the area of sensors and diagnostics that may make it possible to monitor and predict the behavior of many components and subsystems of nuclear units. Further, the explosion in information processing capability suggests that many of the functions of data collection, trend analysis, and early warning can be automated.

With the stakes so high in the nuclear world it seems both timely and prudent to give a new look at improving the science and technology of plant maintenance.

CONCLUSIONS

The purpose of this conference is to identify innovative initiatives that can expand upon existing cooperative activities pertinent to global problems in energy and the environment. I can think of nothing that would be more crucial to the world's future than avoiding a catastrophic nuclear accident. I have tried to present an agenda for research that might contribute to enhancing nuclear safety. Since the technology, and therefore the problem, is international in scope, it is evident that a high degree of international cooperation is required.

I wish to emphasize a particularly important aspect of the need for collaboration. It is entirely possible that the research program I propose could be carried out to a successful conclusion. Indeed, I believe it can be. Yet, the results may be meaningless if operators of nuclear plants fail to adopt changes. And such a failure would completely negate any benefits the research might possess. Thus, I believe that an essential element of the research is the international cooperation that this conference espouses. Without it we may have a classic case of a successful operation but a dead patient.

INSUFFICIENCIES IN SOLVING GLOBAL ENVIRONMENTAL PROBLEMS BY SPECIALIZED SCIENTIFIC EXPERTISE

by

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INTRODUCTION

This conference is concerned with the most paradoxical and urgent problem that faces the world today. We find ourselves between the horns of a dilemma. One horn represents the accelerating demand for energy, and the other, the irreversible degradation of our natural environment.

We have been called together not only to analyze and understand the nature of these extremely serious problems but also to offer aggressive and practical solutions.

There are two directions that we can take to solve our growing global crisis. The first step is to encourage scientific specialists to think in broader terms. The second necessary approach is to make decision makers aware of the complexity of the situation as well as the dangers of tunnel vision that experts often fall into. Therefore, to find a long-term holistic solution, decision makers, be they government officials or academics, must be, themselves, solution oriented and capable of directing scientists along broadened problem-solving pathways.

Up till now, scientists have been required to research environmental problems, discover causal associations and determine effects. Contemporary scientists, in the truest sense of the meaning, are no longer generalists but are specialists in their own fields with great depth and accuracy of knowledge. However, experts of high standing may have difficulty visualizing adjacent sciences, which causes them to lose sight of topics peripheral to their main field of interest.

The consequence of this can be that solutions to a problem will be sought only within particular and specialized areas, but it is, unfortunately, a fact of life that environmental problems do not come neatly packaged in scientific disciplines: they happen in their entirety, with all their synergistic implications. Further, scientists often dwell on the causes of a problem, immersing themselves in intellectual challenges and stimulation, and only to a lesser extent do they search for practical solutions.

There is also a practical side to the academic aspects of research promotion. Research promotion, particularly for new ideas, comes about through grant proposals to sponsoring agencies. It is standard procedure that proposals for new research will be submitted to a sponsor who will, in turn, have them reviewed by specialized scientists. The likelihood of a research grant increases with the specialization of the proposer. General overviews are not in vogue, for they are too easily linked with being unscientific.

Further, it is our opinion that a problem of perception seems to have arisen, at least in the Federal Republic of Germany. We strongly suspect that similar confusion exists everywhere in the industrialized world. There are areas, particularly in energy production, that seem to be taboo—although not officially

and explicitly—but nevertheless, factually, that are caused by the media, public opinion and psychologic attitudes.

National production of coal, as an energy supply, seems to be one of these off-limits topics. As coal is the only significant source of energy resource in Germany, it seems to be more difficult to fund projects that are, in any way, opposed to the coal policy, although this is not actually stated as such.

For reasons of public emotions, it is hardly possible nowadays to defend the environment—friendly aspects of nuclear energy, relative to coal production. This also has a negative effect on scientific research.

These three factors—specialization, research funding and public emotions—are influences, in our opinion, that should not be underestimated in the field of environmental sciences—at least as far as we can judge from the situation in Germany.

Although we live in a time of nearly unlimited opportunity and freedom of information, nevertheless, there seems to be resistance to pertinent answers to urgent environmental problems that can only be resolved through improved international political and scientific cooperation.

We believe this to be a surprising state of affairs, and we shall therefore discuss the following four examples to explain our view.

A. To the Problems of Research into Forest Extinction

Although the general public is only partially aware, the extinction of the forests in the German Federal Republic, as well as in many mid-European countries and North America, represents one of the most serious environmental problems today.

The 1988 statistics on damage to forests in Germany show the following:

A1 47.6 % of the total forest area is without damage,

A2 37.3 % fall into damage category No. 1,

A3 13.8 % fall into damage category No. 2,

A4 1.3 % fall into damage category No. 3 & 4,

by category 4 depicts forests that have completely died off. The classifications are relevant to the total forest area and include every type of tree.

Air pollution through energy production from fossil fuel is without doubt one of the major reasons for the state of our forests today. This is clearly apparent as the acidity of soil in the German Federal Republic is gradually increasing.

Figure A1 shows the changes of the pH values in the soil of the state of Nordrhein-Westfalen during the period 1959/60 to 1981.

It is apparent that even soil of already high acidity has increased even further in acidity. The decreases of the pH values range from 0.12 to 1.15.

On the other hand, it is widely accepted that no single specific substance is responsible for the destruction of our forests, and synergisms play an important role in the total scenario. For this reason, there are quite a few research projects that are currently investigating this problem at length.

With regard to the thesis that was mentioned in the introduction, it is our opinion that these research projects will produce a considerable amount of valuable scientific knowledge, but because of the present approach to the problem, these projects will not bring us closer to solving the problem.

By oversimplifying we provide the following as a hypothetical example of current research projects: Let us assume that acid rain (generated from SO_2 and NO_x) is largely responsible for the damage. Let us therefore discuss the situation relative to SO_2. In the German Federal Republic total emission of SO_2 broken down into sources, is as follows:

Table A1
Yearly Emissions of SO_2
In the Federal Republic of Germany

	1966	1970	1974	1978	1982
Total emission in 10^6 tons	3.2	3.6	3.6	3.4	3.0
			Share of Sources in %		
Power plants	41.3	45.9	51.3	55.1	62.1
Industry	37.7	32.3	30.0	27.8	25.2
Private households	19.9	18.6	15.3	13.4	9.3
Highway traffic	3.1	3.2	3.4	3.7	3.4

To reduce pollution, Germany has introduced legislation that necessitates investment for emission-control equipment of about DM 20. 10^9 (Deutsch Marks) in the fossil power-plant sector. The predicted success up to 1993 reduces the emission by fossil power plants to below 0.5 10^6 tons—other sources remain unchanged. Therefore, the total emission in Germany will be reduced by less than 50%.

Unfortunately, this 50% emission reduction will not produce a corresponding reduction in air pollution, as only 50% of the air pollution load originates in Germany, as table A2 will show. This means that an expenditure of DM 20. 10^9 will only produce a reduction of less than 25% of the SO_2 which is minimal.

The conclusion to be drawn from these figures, therefore, has to be that it is not sufficient to engage in single-cause research into the reasons for the extinction of our forests. We must anticipate *before* and *during* these research programs what can be achieved with the results obtained. It very well may be that we know the reasons after finishing the project but have no tools to solve the problem.

To prove our point, we looked into 117 publications—almost all published during 1987/88—but we did not find realistic answers for retarding the spread of forest extinction. Good science, yes, but hardly practical solutions.

What is therefore requiredis: research far beyond the individual scientific province; cooperation not only beyond political boundaries but also throughout the sciences coupled with a synergistic view of the problem, even if that may sound somewhat less scientific; and more consideration given to the possible practical use of scientific output.

B, Environmental Risk of Final Storage of Hazardous Wastes

This example has some relation to example A.

There have been bitter arguments in recent years among the general public, politicians and scientists over recycling waste products of fuel-driven nuclear power plants as well as over the final storage of radioactive waste. Some members of the general public as well as scientists foresee a long-term danger to the population and the environment through radioactive contamination in the event of accidental emission on a large scale or long-term diffusion from deep-layered storage facilities. The argument is that radioactive components such as Pu, have a long half-life, thus producing unacceptable long-term risks.

The Chernobyl accident has created an enormous emotional reaction to the risk of contaminating soil in Germany, which, nowadays, makes it very difficult, if not impossible, to produce a factual risk evaluation and decision on safety.

We are once again of the opinion that a single analytical evaluation of soil contamination due to nuclear technology from final storage, from power plant use or from an accident is not sufficient to produce a factual risk or safety decision. If we are going to approach this issue in a logical manner, we have to weigh the risk of the alternative energy-producing technology, which, in Germany and the western world, means the use, or increased use, of coal.

Just as in nuclear energy, the use of coal also presents a final storage problem, although it is not generally acknowledged. Table B1 illustrates the enormous amount of waste produced by the coal industry.

In this conference the waste material CO_2 was already mentioned as a global threat. As far as SO_2 is concerned, during the past 30 or 40 years, more than 3 million tons of SO_2 or its oxidation products are emitted each year. The surface of the German Federal Republic covers approximately 1/4 million km^2, which means that for each year over each 1 km^2, 15-20 tons of sulphurous compounds (depending on the type of compound) are deposited in the soil, or to put it another way, the past 50-60 years were sufficient to deposit at least 1000 tons of sulphurous compounds per 1 km^2 into the soil. The figures are similar for other waste products of coal, as well. The increased acidity in the soil, as shown in figure A1, is a direct result of this situation. These facts have to be taken into account when the storage problem of nuclear matter is being discussed, since in Germany and most western countries, only coal offers an energy alternative for the next 20-30 years. Therefore, it is very likely that the risk from the coal alternative to waste production of the nuclear fuel cycle is much higher than the hyperbolic discussion of the risk of radioactivity. Or, in simple terms, the treatment can be more deadly than the disease.

Scientists ought to look for solutions to the problem on an integral long-term basis that considers the alternatives rather than merely taking an analytical view of a singled-out problem such as nuclear waste.

C. To the Problems of Ozone Reduction

Since late winter/early spring 1980, ozone reduction has been observed over the Antarctic (Farman et al.) which has caused increasing concern among the general public.

Figure C1 demonstrates a yearly cycle of the total ozone over the South Pole in a mean-value curve for the period 1964-1979 and again for the period 1980-1985.

In addition, figure C2 is a chronological illustration of ozone profiles from balloon-borne ozone soundings. Both figures are the work of Robinson (1988) and clearly show the development of the hole in the ozone layer, firstly over a period of the last three decades and then in relation to seasonal developments.

The general ozone problem, as it is known to scientists and laymen, was first made public by the since famous work of Molina and Rowland (1974). It is now well-accepted knowledge that chlorofluoromethane, mostly produced as CFC-11 and CFC-12 and chemically hardly reactivated in the troposphere, contributes

to the destruction of the ozone layer in the stratosphere. To understand the phenomenon of the ozone hole over the Antarctic, four *dynamic* aspects have to be appreciated. These are:

- Why has it only appeared—or been discovered—in the past 10 years?
- Why is it a seasonal cycle, whereby every year ozone reduction is strongest in October, and mainly over the Antarctic?
- Why is the largest reduction between an altitude of 15 to 20 km and not a gradual general decrease?
- Why—as one participant of this conference pointed out—do the latest ozone soundings seem to indicate a far smaller reduction?

That the ozone reduction has become apparent only during the last decade could be explained by the gradual increase of CFC11 and CFC12 concentrations in the stratosphere. Keeping this in mind, a quasi-steady-state phenomenon with slow concentration increase could be observed by exceeding a threshold of detection.

But the annual seasonal appearances of the ozone hole and its boundaries at the Antarctic region and the possible yearly variance in reduction are such pronounced dynamic effects that an explanation is far more difficult and, up to now, not fully completed.

Currently, the main line of explanation for the ozone hole seems to be (Kerr 1987) that it is a result of stratospheric chlorine chemistry (CFC11, CFC12, N_2O, ClO, ...) in the presence of polar stratospheric clouds in an extremely cold Antarctic stratosphere cut off by a strong and persistent circumpolar vortex from mid-altitude sources of ozone and heat.

In that explanation we are lacking at least some logic about the possible causes of an alteration of the governing dynamic effects—which we mentioned previously in opposition to effects of stratospheric chemistry. During the discussions of this conference, participants agreed that dynamics are indeed important and should be further researched.

On the other hand, it is obvious that we can expect increasing dynamic changes due to the CO_2 problem in the atmosphere.

Figure C3 illustrates changes in the distribution of temperatures for doubles of the CO_2 content in the atmosphere, which is demonstrated by two separate computer models for fixed and variable clouds, respectively. These examples are taken from the DOE-CO_2 climate report by M.E. Schlesinger.

Details are not important at this point. What is significant is that a global increase in temperatures at ground level is predicted, whereas the temperature at the stratospheric level will decrease for many latitudes. As part of the climatic effects, a gradual redistribution of temperature and heat sources will take place, no doubt followed by redistribution of circulation sources and dynamics. This obviously also applies to oceanic conditions and climate.

In our opinion, this information has to be looked at in connection with the dynamics of the ozone hole. Whether or not scientists agree with the reasoning of this line of argument is not the point of the discussion here, although in our experience we have not found much support for this.

We are once more deeply concerned that an environmental problem—in this case, the hole in the ozone layer—is evaluated correctly but, in terms of science, treated too narrowly relative to the solution of the total problem.

As you know, quite a few international ozone conferences have endeavored to restrict the production and use of CFCs particularly in aerosol cans, or if not prohibit, then at least reduce their consumption. In

our opinion this is not enough. We have to look at the ozone problem in light of the CO_2 problem, even if the connection is not totally proven at this point. Otherwise we may find ourselves in the alarming position, scientifically and politically, of doing the wrong thing now, a situation that may be irreversible in 20 years' time.

It seems to us that the German Federal Republic as well as many western countries show an emotional barrier against such considerations.

D. To The Tropical Rain Forests

The rapidly increasing destruction of the tropical rain forests over recent years has been of increasing concern to the general public.

In Germany, Parliament, in a unanimous vote, delivered an appeal to halt the cutting of these forests.

We agree with individuals who see a danger in the felling, burning and uncontrolled annihilation of these forests. But here again, the situation has to be looked at synergistically together with other environmental factors and not be based on a public-opinion-oriented monocausal discussion.

The destruction of the rain forests is serious because it eliminates a unique biotope and robs the thin humus soil layer of its protection, turning it into desert after a short period of agricultural use. More importantly, however, it upsets climatic conditions not only locally but on a global scale. It affects the albedo as well as air humidity and temperature and thus circulation.

The Federal Republic of Germany and other industrial countries are involved in a campaign to condemn countries who have no policy for guarding their own natural resources, the tropical rain forest. These countries are being accused of materialism and reaping economic benefits from the export of wood and forest-clearing for agricultural purposes.

The global climatic consequences of the destruction of the rain forests are greatly compounded, however, by the changes in climate brought about by the total emission of infrared-active gases by industrial countries.

Industrial countries, particularly the German Federal Republic, are unwilling to change their industrial policy on emissions for economic reasons—yet they accuse countries with tropical rain forests of the very same exploitation for economic gains of which they are equally guilty.

In our view, a scenario exists that barely allows for a solution due to a one-dimensional overriding attitude. Once again, a holistic, integral approach by scientists in evaluating the situation would be considerably more helpful than analyzing only one segment of the total problem.

CONCLUSIONS

We have shown four examples from widely different scientific fields in which it is evident that too narrow an approach prevented or prevents a solution of the environmental problem. The approaches in these examples were scientifically but, to a lesser extent, solution oriented. The reasons for that situation are, in our view, manifold.

An important part—as already mentioned—may be the high degree of specialization of most scientists, in addition to the fact that the governing attitude is to improve science and not to solve practical problems.

Another part is the manner in which science is sponsored in western countries, which favors the roles of specialists and, to a lesser extent, the generalist—the latter of which may be viewed as unscientific.

Unfortunately, public perception significantly influences research, which may explain the neglect of some research areas.

We do believe that a wider approach is necessary to resolve our global environmental problems.

We conclude with a phrase that we saw quoted in one of Roederer's (1985) papers. "He who understands nothing but chemistry does not truly understand chemistry either."—Georg Christoph Lichtenberg (1747-1799).

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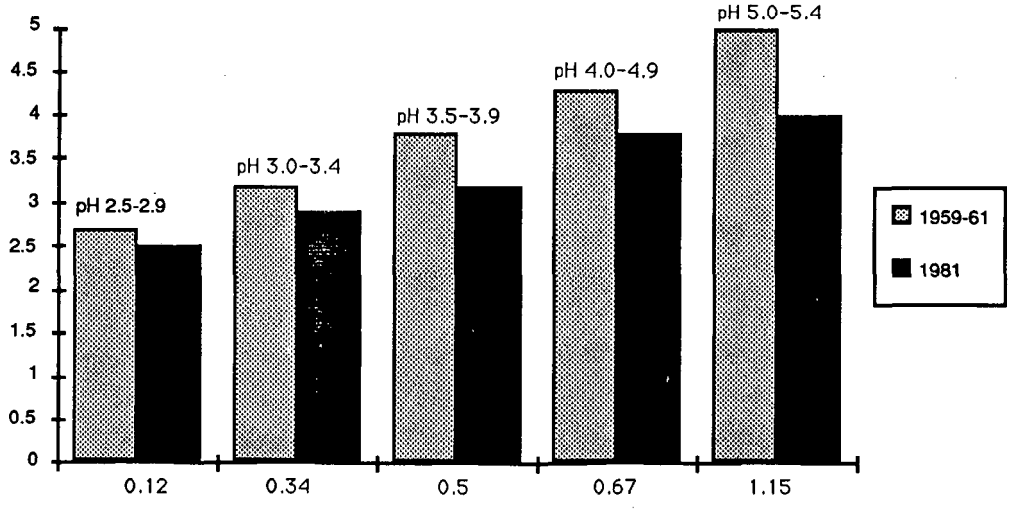


Figure A1: Change of pH value over 20 years in forest soils in Nordrhein-Westfalen.

Table A2
Deposition of Sulphur in the Federal Republic of Germany from other Countries

Country	Kilotons sulphur per year	%
Belgium	44.4	3.5
FRG	673.2	53.3
Denmark	4.8	0.4
GDR	141.6	11.2
France	129.6	10.3
Great Britain	86.4	6.8
Italy	28.8	2.8
Yugoslavia	18.0	1.4
Luxembourg	6.0	0.5
Netherlands	27.6	2.2
Austria	9.6	0.8
Poland	21.6	1.7
Spain	7.2	0.6
Czechoslovakia	57.6	4.6
Hungary	7.2	0.6
$\sum$	1 263.6	100

* Amount of emission originated and remaining in the Federal Republic of Germany.

Table B1
Average Amount of Emissions due to the Burning of $10 \cdot 10^6$ Tons of Coal

Amounts of emission in tons	Substance	Characteristics
30 000 000.	carbon dioxide	
100 000.	sulphur dioxide	
100 000.	nitrogen oxides	
10 000.	hydrochloric acid	
4 000.	carbon monoxide	
1 000.	fluorine hydrogen	
8 000.	air-borne ash	
10.	heavy metals	carcinogenic
1.	benzopyrene	substances
0.001	uranium	"
	dimethyl and	"
	monomethyl sulphur	"

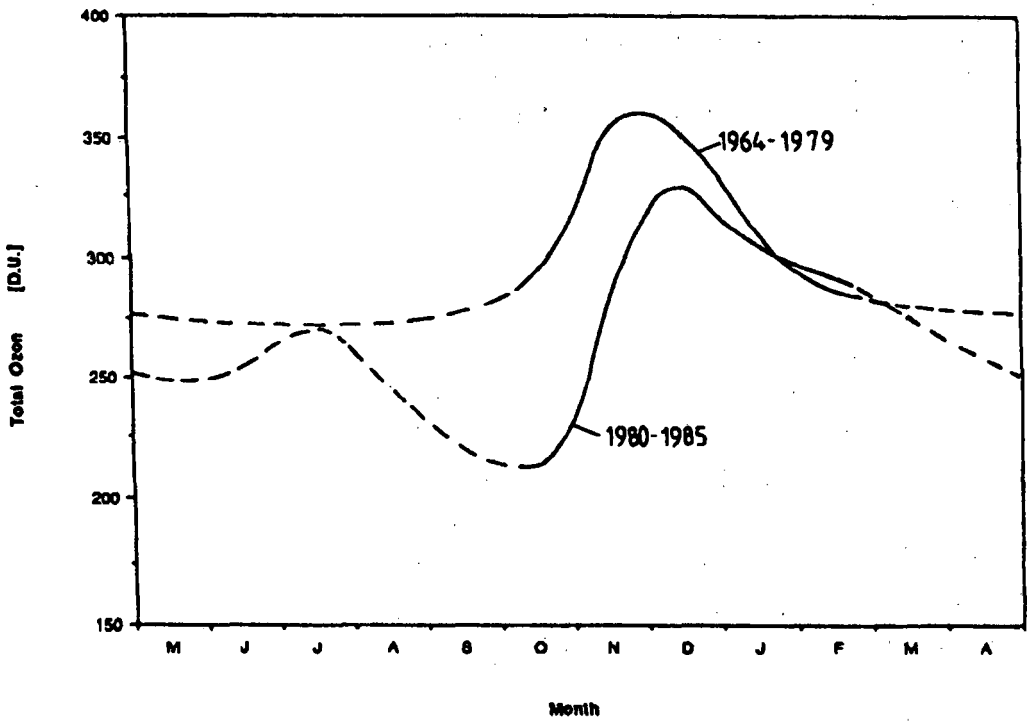


Figure C1.

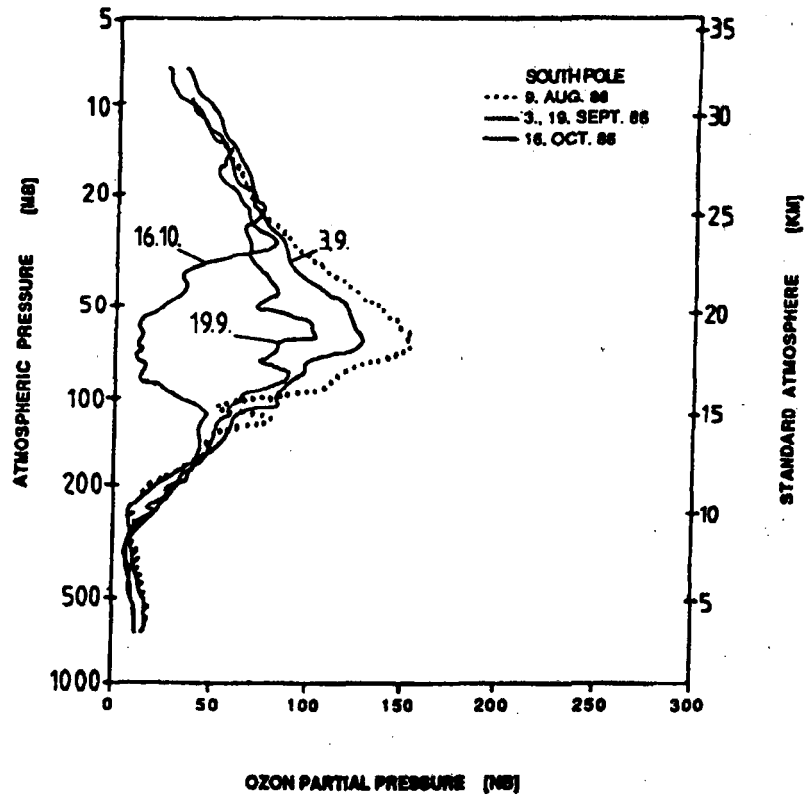


Figure C2.

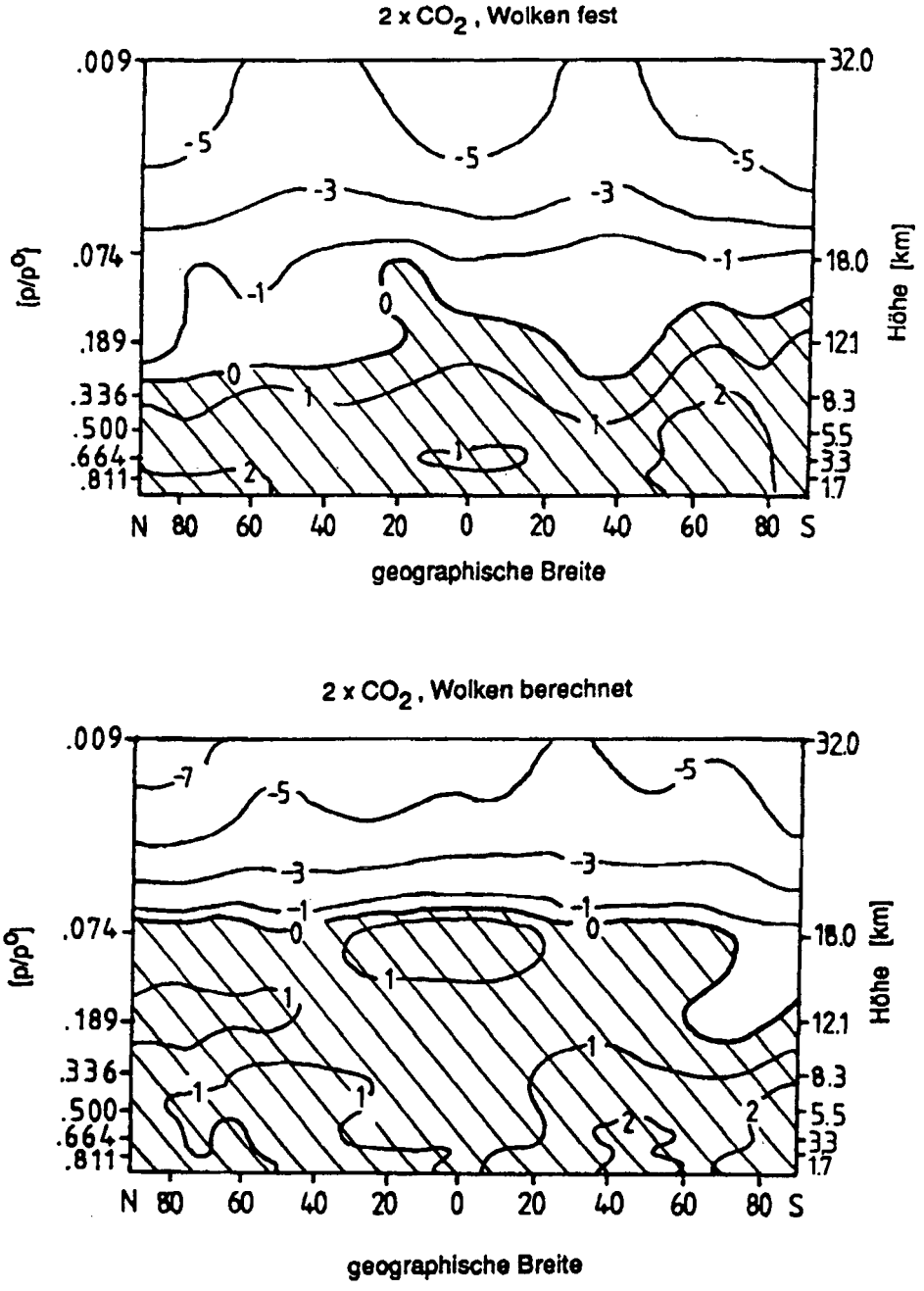

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Figure C3.

SOLAR ENERGY AND THE GLOBAL COMMONS

by

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THE GLOBAL COMMONS

In today's world we find ourselves grappling with issues whose resolution will not be possible without international dialogue and cooperation. The pressure of increasing world population, the threat of nuclear conflict, and impending global climate change respect no national boundaries. Along with the management of the oceans and space, these issues demand unprecedented levels of cooperation, trust, and confidence among the world's community of nations.

When I began to wrestle with the topic of this conference, "technology-based confidence building," across national boundaries, I realized energy is the thread that runs through most of the global issues we face today. Modern energy technologies make the world run. They are as vital to developments in communications and weaponry as they are to economic and political stability. They make possible the tools we need to manage and develop our planetary resources.

Conventional energy technologies are also extracting an increasingly high price from our natural environment. Air pollution, acid rain, and the depletion of the ozone layer are all linked to our use of energy. Climate change is expected due to the accumulation of greenhouse gases in the atmosphere and poses an awesome challenge to humanity over the course of the next 100 years.

Such serious environmental problems mean solar and other unconventional energy technologies must play key roles in our global energy future. Deployed as part of international strategies to slow global warming, they will deliver energy to industrial societies and developing nations alike.

Still, it's naive to assume that technology alone can solve today's complex environmental, economic, and social problems. Deforestation, the threat of nuclear conflict, economic equity, and global warming all have technological dimensions. Most of the time, it's easier to deal with the technological side of things than the social and political realities that accompany them.

But, as people from different nations begin to work on the technical aspects of these problems, we're likely to discover that we have concerns and common values. Regardless of individual political philosophies, we find common ground in ensuring that our air, soil, and water continue to support human life. We find few dissenters in the search for an improved quality of life, which presses us towards conservation, population control, waste management, and sharing the benefits of technology.

As we apply these values to finding technical solutions to our common problems, we will find that we can, indeed, work together. In a sense, technology provides the basis upon which we can build confidence in each other across the diverse interests of individuals and nations. From this common vantage point, we can begin to map out constructive strategies for dealing with those issues that should be addressed through international cooperation—issues that Harlan Cleveland has called the global commons.(1)

The concept of the global commons encompasses issues and resources that cannot be naturally or conveniently subdivided. Space, the oceans, sunlight, weather and climate, and the continent of Antarctica belong to the world's peoples. No individual, group or nation can aspire to sovereignty over such resources.

Widespread international cooperation is required to govern and manage their use. Similarly, global warming, equity, nuclear conflict, and the increasing population cannot be dealt with in the absence of global cooperation.

Our shared access to information (or misinformation, as the case may be) binds the global commons together. It gives us the tools we need to begin to weave global solutions from the diverse histories and values of many nations. Let me give you an example.

In April, I attended an energy conference in Paris sponsored by the International Energy Agency (IEA) and the Organization for Economic Cooperation and Development (OECD). The conference looked at the effect that energy use and production has on the accumulation of greenhouse gases. It explored ways to use energy technologies to reduce the emissions of greenhouse gases, especially carbon dioxide. As a result of this exchange of information, the conference began to define the ways in which the international community could cooperate to mitigate climate change.

From the beginning of the meeting, it was evident that public pressure is rapidly forcing OECD governments to consider energy and the environment as interrelated issues, that these issues demand international attention and cooperation, and that solar energy has a major and particular role to play in all this.

Declaration of Interdependence

Listening to a myriad of confusing and sometimes conflicting techno-economic analyses at the Paris IEA Conference prompted me to capture the challenge of facing the Conferees in a short list of basic truths, which, with apologies to Thomas Jefferson and the founding fathers, I call the Declaration of Interdependence:

We hold these truths to be self evident:

- The world is created as one intricately balanced physical and biological system.
- Energy supply and use are dominant factors in humanity's growing impact on environmental quality.
- The nations of the world are endowed with certain inalienable rights among which are the pursuits of national security, economic development, equity, and well-being for their people.
- Governments and individuals will rarely pay a near- term economic penalty to solve long-term concerns.
- Plentiful energy is essential to modern economic and social systems.
- Energy security and environmental quality are global concerns.
- When energy production and use become destructive to the environment, it is in the interest of the international community to cooperate in abating the damage.
- OECD nations have a special responsibility to develop new energy technologies and facilitate their implementation in their own and less developed countries.

The Priorities of Nations

There is, of course, another truth—world population continues to grow geometrically and is projected to reach 8 billion by the year 2030.(2) This will increase the demands on Earth's resources, exacerbate waste disposal problems, multiply the requirements for food and energy, and elevate greenhouse gas emissions. As nations struggle to provide for the basic needs of their people, these needs will undoubtedly take precedence

over the more distant concerns for the environment. That's a major reason global environmental problems are so hard to temper—nations attend first to more pressing problems.

Nations generally put national security at the top of their list, followed by political and social stability. Only after these problems are addressed do questions of economic vitality and environmental quality come to the fore. Today, most nations are dealing adequately with security and stability. Consequently, most are preoccupied with economic growth. They are reaching for a better standard of living and striving to be competitive in international trade. Since each nation is looking for an advantage, international cooperation is the exception, not the rule.

But nations must cooperate to insure the well-being of the global commons. Unfortunately, energy security and environmental quality are not yet considered to be pressing issues. However, they are critically important to a sustainable future. If we do not confront them, the political and social stability of all nations will suffer.

The challenge is to find global strategies that both protect environmental quality and provide for reasonable economic equity for the peoples of all nations. Equitable economic opportunities require access to affordable, abundant, and reliable energy resources. Solar or other renewable energy systems should be made available to developing nations, whose energy consumption is rising rapidly. Financing problems, currently a major obstacle to the introduction of new energy technologies, must be overcome. Otherwise, the use of oil and coal will continue to escalate, greatly increasing the emission of global warming gases and exacerbating the threat of disruptive climate change.

Renewable Energy Technologies

Renewable energy systems can supply energy at reasonable costs, have minimal environmental impact, and draw from an enormous resource base that is accessible to all nations. Using new energy technologies, for example, the United States could harness sunlight to produce more than 250 times as much energy as we use today. Other nations have equal access to these energy stores.

Renewable energy technologies can be used practically anywhere on Earth, on any scale, for any application. They can produce energy in all necessary forms—electricity, heat, light, or fuels.

In addition, renewable energy is a major part of the solution to many environmental problems: acid rain, ozone-layer depletion, deforestation, and waste disposal. In fact, conservation and renewable energy are the most effective options for ameliorating climate change due to global warming. For industrial nations, conservation offers a means to curb already large energy appetites. For developing nations, renewable energy is one of their best options for meeting their growing need for energy.

CURRENT ROLE

The story of renewable energy is just beginning. Since 1970, the United States has increased its consumption of renewable energy by about 50%, from about 4 quads to more than 6 quads.(3) Renewable energy now accounts for about 9% of all domestic energy sources.(4) Hydropower and the burning of wood and wastes each account for approximately 40% of the total U.S. renewable energy consumption.(4) Passive solar design and solar hot-water heaters and emerging technologies like biofuels, waste-to- energy systems, wind, geothermal, and photovoltaics comprise the remaining 20%. A recent analysis performed by the

Solar Energy Research Institute suggests that increased governmental support for renewable energy could triple its use by 2010, to almost 20 quads.(5)

The introduction of renewable energy systems could take place even more rapidly in the developing nations. All have ample resources, including sunlight, falling water, wind, heat within the earth, plants, and wastes. Emerging renewable technologies are not only well-suited for the dispersed applications that predominate in much of the world, they are also cheaper than conventional technologies for these applications. Versatile, modular, and easy to use and maintain, renewable energy systems could become a major component in the world's energy infrastructure.

International cooperation is the key to bringing this about. Large amounts of capital and political support are needed to advance these new technologies and demonstrate their utility. OECD and the developing nations must add the environmental costs of conventional energy technologies into their energy planning and economic analyses. World leaders should take steps to foster the growth of renewable energy industries. And, as nations take important steps toward implementing these new energy technologies, they should share ideas and strategies with one another.

The well-being of the global commons demands a rapid transition to renewable energy. If we proceed with "business as usual," these new systems won't be operational in time to meet the growing energy needs of developing countries. Unless developed nations accelerate their efforts to bring renewable energy technologies into the global energy infrastructure, Third World nations will continue to commit their limited capital resources to fossil-fuel based energy. The global use of fossil fuels will climb unabated until constrained by supply and high prices. The accumulation of greenhouse gases will lock us into climate fluctuations of unprecedented magnitude.

In contrast, if we work together to show that renewable energy technologies are reliable and competitive and to establish a supporting infrastructure, we will see an influx of capital and a corresponding increase in industrial interest and political support. This will allow renewable energy systems to enter the world economies in a substantial manner. And we will have taken a giant step toward curtailing the emissions responsible for the climate changes that threaten us all.

THE POTENTIAL OF RENEWABLE ENERGY

To understand the enormous potential of renewable energy, it is instructive to look at a few specific technologies: biofuels, solar thermal technologies, and photovoltaics. Biofuels technologies transform plants and wastes into valuable fuels, including "natural" gas, alcohol fuels, and gasoline. Solar thermal technologies provide space heating and use concentrated sunlight to produce industrial process heat and electricity. Photovoltaic systems change sunlight into electricity to power everything from consumer products to domestic appliances, dispersed power systems, and large-scale electrical power production.

Photovoltaics (PV) has progressed dramatically since the United States began its terrestrial PV program in the mid 1970s. Originally an exotic power supply system for spacecraft, early PV systems were incredibly expensive compared to today's systems. Single-crystal silicon was the only PV material used. Cells made from it were relatively inefficient.

Since then, the U.S. research and development program has made terrestrial photovoltaics a reality. Costs have plummeted more than 40-fold. New materials, including amorphous silicon, copper indium diselenide, and gallium arsenide, now compete with single-crystal silicon for most applications. PV devices are more efficient and reliable. As a result, tens of thousands of PV systems are now used worldwide,

powering applications as diverse as water pumping for irrigation in the Sudan to central power generation in California.

This is just the beginning. Within a decade, we'll see high-efficiency, long-lived modules in place. U.S. utilities will install megawatts of PV systems to generate peaking power. At the same time, the price for PV electricity is expected to drop to $0.06 per kilowatt-hour, making it competitive with conventional electrical power generation. At these prices, PV will be the preferred option for dispersed, remote, and specialty applications.

There are things we can do to speed up this process. By making PV research a national priority, we could open the door to making photovoltaics the preferred option for baseload electric power and put the U.S. in a position to supply a growing market in dispersed power systems in the developing countries. Eventually, we may find a way to use photovoltaics to produce hydrogen. Inexpensive hydrogen would be valuable for industrial applications, for energy storage, and as a transportation fuel.

New biofuels technologies can supply us with transportation fuels as well as energy for other purposes. In biofuels R&D, we're learning how to harness the energy stored in plants and wastes. In the process, we're also finding ways to increase the absorption of carbon dioxide from the atmosphere. The result is alternative fuel technologies that can displace significant amounts of petroleum and reduce greenhouse gases and acid rain.

Ethanol, perhaps the most environmentally benign liquid fuel known, is one of these alternatives. In the United States, we still make most of our ethanol from corn. Our use of corn ethanol has grown from 10 million gallons in 1979 to 840 million gallons in 1989.(6) Brazil has an even more impressive track record. It uses sugar cane to produce more than 2.6 billion gallons of ethanol per year—enough to run most of its transportation fleet.(7)

Mindful of the problems that can arise when food production competes with energy production, however, our research program has focused on making ethanol from wood. Wood is renewable, can be farmed, and is suitable for land that is marginal for food crops. By deriving ethanol from wood or wood wastes, we can meet our need for transportation fuels while reducing stress on the environment. (Wood removes more carbon dioxide from the atmosphere during growth than wood-derived fuels emit when burned.)

In a decade of R&D, we have learned how to convert more than 70% of wood to ethanol and have lowered the costs of the process from $4.00 a gallon to $1.35 a gallon. We feel confident that another 10 years' effort will lead to 90% conversion rates and costs of $0.60 a gallon. This is comparable to $25.20 per barrel oil and compares favorably with DOE oil price projections of $28.00 per barrel oil for the year 2000.

Ethanol is only one part of our biofuels research objectives. We're also finding ways to derive crude oil from wastes or wood crops and produce gasoline and high-octane additives from this crude oil. We're learning how to make methanol transportation fuels and methane (natural gas) from plants and wastes.

Our long-range research is creating a revolution in biofuels technologies. The future will see us cultivating and harvesting algae for oil, perhaps even genetically engineering algae and phytoplankton to remove large amounts of carbon dioxide from the atmosphere. New photobiological techniques may also yield an economical method for making hydrogen.

We're also working to unlock the secrets of photosynthesis and make it more efficient—not only for producing food but also for making energy products. From this single avenue of research, we may one day meet a growing population's two most basic needs.

The future also holds great promise for solar thermal technology. Already used to generate electricity and heat for industry (California has 200 MW installed capacity and 300 MW planned), solar systems can also be designed to treat hazardous wastes and contaminated water.

There are several other renewable energy technologies under development in the United States. We have ways to capture the energy in wind, in the Earth's heat, in sunlight, in falling water, in the oceans, in plants and wastes—in whatever renewable resources are available to any nation. With a concerted international effort, we can make a transition to environmentally benign renewable energy systems around the globe.

Like conventional technologies, renewable systems can provide us with electricity, heat, air-conditioning, refrigeration, and light. They can turn our garbage into energy and destroy wastes. And, in the process, they will help ameliorate acid rain, stop ozone depletion, and slow climate change. Eventually, renewable systems will produce food, fertilizers, industrial chemicals, drugs, paper products, biodegradable plastics, fibers, and building materials.

The Case for International Cooperation

If we are to effectively address the problems of world energy sufficiency, environmental degradation, and global climate change, we must accelerate the penetration of renewable energy systems into the global energy infrastructure. This means each nation must intensify its research and development. And, we must seek practical avenues for international cooperation. The issues we face transcend national interests and national borders.

If we find it difficult to collaborate because of proprietary interests, then we must work together to set common goals and priorities. If we find it difficult to participate in the development of specific technologies, then we can seek our common ground in the basic sciences that precede technological development. We can also work together on resource assessment and deployment policies and strategies. In this vein, I would like to outline specific ways in which nations could promote collaboration and cooperative projects:

1. Coordinate research and exchange information in basic sciences relevant to emerging renewable energy technologies. Such research collaboration might include:
   - Photochemistry, with an emphasis on carbon fixing, synthesis of energy-rich chemicals, or photodestruction.
   - PV materials, microstructure and mechanisms that limit conversion efficiencies.
   - Photobiology, with an emphasis on engineered organisms to produce hydrogen, ammonia, or other energy-rich chemicals.
   - High-temperature superconductivity, developing its potential for energy storage and improving energy-use efficiency.
2. Collect and share information about renewable resources, including solar radiation, wind, water, geothermal, ocean thermal, and biomass. With biomass, for example, both developed and developing nations could gather and share data on energy crops, reforestation, desertification, and the use of biofuels.
3. Establish an on-going international forum on the production and use of hydrogen. Sharing experience and progress on the development of this clean, safe, and unlimited fuel would benefit the global commons.
4. Develop strategies for fostering the use of renewable technologies in developing nations. OECD and Third World nations need to work together on technology transfer, joint ventures for the manufacture

and distribution of renewable energy systems, collaborative research, financial packages, information exchange, and resource assessment.

5. Provide consensus input on conservation and renewable energy to computer models analyzing global warming. If we do this, the models may be better able to assess the effect of policies to deploy conservation and renewable energy on mitigating the severity of climate changes. If successful, this cooperative effort could be extended to other issues affecting the global commons, such as acid rain.

CONCLUSION

We are all inextricably bound into the global commons. It will require our cooperative efforts to successfully resolve such global issues as economic equity, population increase, energy production and consumption, and environmental degradation. The world's passage into the future virtually demands a revolution in energy technology and the way we use energy. We must turn more and more to energy technologies that harness our common resource—the sun. That way, modern societies can exist in harmony with the world, powered by technologies that engender not just our standard of living but our quality of life.

This change will require unprecedented levels of cooperation among nations. Our common future demands research collaboration, information exchange, and creative strategies for introducing renewables into the world energy infrastructure. We must strive together to understand our remarkable solar resource, manage our planet's physical and biological heritage, and create a sustainable environment for our children and grandchildren. To do so means we must build confidence and trust in one another—however difficult that may seem. I think Former U.N. Ambassador Soedjatmoko of Indonesia summed it up for all of us when he said,

"We are bound together in a common future. We must blunt the rough edges of national sovereignty in the interests of human solidarity, human survival, and human rights."(8)

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SUMMARY ADDRESS

SCIENCE, TECHNOLOGY, AND WORLD AFFAIRS

by

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In attempting to sum up some of the deliberations of this conference, and I expect that is what I am to do, it would be best first to say why we are all here. We are here because the world is passing through a transition. With good authority it has been said that the Cold War is over. Now that a war is over, you have the victors and the vanquished. You know who won—Japan and West Germany. I suppose you can guess who lost. That is why we are now disarming ourselves. Losing this strange war is just as strange as fighting it. The war was never fought outright. The great instruments of destruction first born here in New Mexico were never used, the rockets never took to their deadly course. At great expense we were deterring each other, finally escalating the arms race to such a level of armaments that a mere fraction of what is now available would bring us beyond any imaginable limit of destruction.

If the balance of power were spelt by the numbers of units, it is well known that the wars were and are fought by soldiers. There the practical military experience of our countries is revealing, for the last two real wars have been lost, lost in the old way of humiliation and retreat from countries that are now suffering from deadly scars of a modern armed conflict. Without even using nuclear weaponry, or other very sophisticated arms, what was left was not much different from the aftermath of a total war of attrition and destruction without resolving any of the social or political issues that were the proffered reason for the war.

I do hope that these experiences provide sufficient evidence to prove the futility of modern military might, and that is really why WW III was lost unfought. In our country, perhaps more than others, we see the consequences of defeat: economy in disarray, inflation, drastic necessity for basic changes, and a loss of ideas, ideals and ideology for that matter. Hence perestroika. But the imperatives for perestroika are not confined to our country.

I am sure that we all now have to change or perish, and the symptoms of crisis as you may guess are not unique. Moreover, I do think that the recognition of the transition through which we are now passing is not based only on military terms. I think the military impasse is only a vivid demonstration, a way in which this modern crisis is so obviously expressed.

The reasons for this imminent change lie deeper. They date back to the last century. It was then that modern technology and science-based industry appeared and so powerfully showed its promise that we started to believe that to all problems of our lives we can and should provide a technological solution. For 100 years of remarkable progress this has certainly worked. But a number of times we have seen that in spite of all technical progress and great scientific discoveries our development has been punctuated by major social disruptions.

The state of affairs in our country to a great extent is due to the rather simplistic if not naive belief in a model of society that really had not much to support it, in idealized notions of human nature, and in egalitarian concepts of a very primitive type. It is a belief in a mechanistic model, a machine, a social device rather than in the evolutionary self-adjusting process that we have seen to be so effective in the

world of life. Perhaps it is here, in the disruption of our social machinery, we now see to what extent our mechanistic approach has proved to be futile. But we still are mechanistically minded, and I think that here, at this meeting, we represent the epitome, the essence of gadgetry of the world. In fact, we could say that at this conference the gadgeteers of the world have united!

It is no accident that it has happened, for the great centers of technical progress, the best and biggest laboratories of the world have come together to discuss, if not our common destiny, how to adapt to a new set of goals. Here we have two problems. The first, and the one for which we are best equipped, are the new developments in technology. In detail and with great imagination, we have considered what we can now expect in the fields of energy and environment, exploration of space, and the safe handling of technology when an accident can easily escalate into a disaster. All this is very exciting, and I am sure that much that was said here will really contribute to these new departures. Our discussions will also help us compare many suggestions and choose our priorities.

But of special importance are the suggestions made by many speakers to pursue these new and in many ways promising developments on an international scale and to expect a transition from confrontation to collaboration. In fact, the concept of the conference is concerned with the idea of confidence, of trust and mutual understanding.

During this conference we have spoken about technology but not much about matters of confidence building. Confidence building is a rather recent and, I must say, clumsy expression.

However, the *concept* of confidence building among nations is really an age-old thing. One of the best ways in which it was done in the past were royal intermarriages. In Europe this was one of the main devices to politically stabilize the divided continent, a way that was practiced for many centuries and that then gradually lost its meaning in the 18th century when the French Revolution happened and the US was founded. One of the best examples of how royal intermarriages were practiced is by the great Russian tzar Yaroslav, who had six daughters. One became the queen of France; her sister married the King of England, who perished at the battle of Hastings; others were married to Andrash, the King of Hungary, to the King of Norway and to a Polish prince. These princesses of Kiev were well educated, and it is no accident that their father is known in our history books as Yaroslav the Wise!

In today's world most of the princesses have departed to the glossy pages of magazines. Now summit meetings establish the personal links that are the essence of all confidence-building measures that were set in the drawing room or bedroom, for that matter, in the past.

Perhaps now we have to find other means to establish trust and understanding between nations, apart from those in business and trade. Such connections always were present and certainly help in establishing understanding. To conduct their business those concerned often evaded political connections and understandably refrained from "meddling with politics." In fact that expression was also used by the founders of the Royal Society, and even today we find scientists and scientific societies that still bring up that old idea, a concept that has certainly helped to keep science out of much trouble. On the other hand, again and again it has and is to happen that science and technology will have to actively enter the field of public matters.

It is becoming increasingly obvious that such activity must occur and we should give some thought as to how it can be brought about. It is not at all enough to simply declare that now, instead of building bigger and better bombs and rockets, we are to change our attitudes and start collaborating instead of competing.

The central issue is our motivation. Are we simply engaging ourselves with the latest publicity event and paying service to the last move in the turbulent, if not erratic and fractal, course of world politics? The step to fractals is not as meaningless as it may seem, for much of modern thinking about fractals and

turbulence began with the classic question of Richardson, "Has wind a velocity?" and its social analog should now be "Has progress a direction?"

I hope this exercise in modern scepticism will not block our deliberations. We do have to seek a way out, and we do have to work together and find common bearings for our progress.

I am not alone in suggesting that it is really environment that marks this direction and sets a frame of reference for our efforts. Environment supercedes energy, for now much of the loss in environmental conditions can be traced to the consumption of energy, although the solution of major environmental issues does require energy in our interconnected world.

In understanding the dimensions of our problems, the interconnectedness and interdependence of our world is a key factor. What is also crucial is that in the last decades we have finally come to live in a common and finite world.

This we see in many fields of life. First we have world science, based on a common set of laws, principles, and facts. We have world trade and industry and are even heading for a common currency in the long run. We have worldwide transportation by air, sea, or land. We have a common communication system and are increasingly led to consider ourselves as belonging to a world village. Finally, we have a common global environment, which we all share and all pollute and for which we have a common responsibility. These issues we consider to be rational.

On the other hand, we are increasingly conscious of our cultural and national identities. In fact, our language and heritage form perhaps the strongest bonds in a world where so much is now mutually generalized and equalized—bonds which many take to be irrational.

In this modern world we have to find a place for the future exercises in scientific and technological progress. We do have to act together to a great extent because the mere scale of our research and development effort is so great. High-energy physics and space research, astronomy and plasma physics, all demand international collaboration. The sciences of the Earth, by the very nature of their object, require a joint effort, and today the ICSU and UNESCO programme on "Global Change" is gaining momentum. Finally, biology has now launched an international research program on the human genome—HUGO—to decipher the $3 \cdot 10^9$ letters of the genetic code of the human being.

I am sure that we can technically manage these projects. In other words we have the means, both human and in hardware, to work on such common goals, and all can contribute in a common effort. But what I think will be increasingly important is to find ways to consistently support this effort.

The arms race in the past was kept going by a primitive and powerful positive feedback mechanism that has led us into the present impasse. I expect those present know well how it all worked and do share responsibility in its outcome. If we now hopefully finally renounce this perilous and defunct device, what will come instead? Will the idealism of collaboration be enough to keep us going? This, I think, is one of the most important issues we all face. Perhaps the most important step here is to develop our attitudes on these matters. All the grand projects that have been discussed here have great promise and we as scientists understand that. But I think we overestimate the extent to which these things are supported by the public and hence the body politic. On many occasions, we see a growing public apprehension to science and even revulsion to technology. Irrationality, religious fundamentalism, and other reactions to reason and progress are gaining ground, to the extent that we all have to take into account this mood.

That is, I think that not only do we have to explore and encourage the efforts of the engineers and scientists but we have to pay due attention to the attitudes towards science and technology of our people, our taxpayers, and our governments.

Once I met Olaf Palme. It was in 1978, and he had just lost his premiership in Sweden over the nuclear power issue. I asked him how it could have happened. He told me—we did not pay due attention to educate our public on these matters.

We all have to explain to our people on all levels what we can do. We must not on any occasion oversell science. We must systematically and sensibly work on the public understanding of science and its promise for our common good. We have also to reconcile our professional egotism with the more general ideas of humanity, of morality, of our common survival and existence. For it is values and concepts that guide people and finally set the bearings of our often erratic and fractal, if not frantic, progress. We cannot on any account break up our human integrity, which is perhaps the last vestige of our social and personal existence.

Thus we can contribute to our future. I do hope that such a future does exist, and we all can add to its security, safety, and our well-being. For there are many pressing issues of a global nature that face us and that we must learn to resolve. I hope we all have confidence in reason, science, and the inventive genius of man. This I take to be the main confidence-building means for our common survival.

RETHINKING OPEN SKIES IN THE INFORMATION AGE

by

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INTRODUCTION AND HISTORICAL OVERVIEW

It is a great pleasure to initiate a personal dialogue with you this morning on the implications of a revised "Open Skies" policy. As John McLucas mentioned in his speech, remote sensing of the Earth is a technological breakthrough that involves everyone in this room—everyone from the social scientist to the physicist and engineer. Therefore, we will all have a role in seeing that remote-sensing policies properly address the global challenges of our time.

Discussing the implications of a revised Open Skies policy also fits in nicely with the emphasis of this conference: technology-based confidence building for energy and environment. Information gathered by remote-sensing satellites can increase confidence between governments and people by identifying common values and common solutions.

Finally, Open Skies is a timely subject to discuss thanks to the revisiting of this concept by President Bush. In a recent speech on U.S.-Soviet relations, the President suggested that the free overflight of reconnaissance aircraft, the essence of President Eisenhower's proposal, could promote greater openness in the Soviet Union and help stabilize the U.S.-Soviet relationship.

While "only" 34 years have passed since an American President first proposed Open Skies, it is interesting to note the tremendous changes that have taken place on a global basis. I would like to suggest that changes in the geopolitical landscape during the last 34 years, along with advancements in satellite remote-sensing and associated information technology, have created new possibilities for national and global security through a revised Open Skies concept.

In one sense, the potential to increase international security and stability through an Open Skies policy has in many ways been demonstrated. Nikita Krushchev's rejection of Open Skies did not stop the process President Eisenhower initiated. For the last thirty years the Open Skies concept has emerged in various forms. The burdens of the Cold War were more than adequate incentive to develop our nation's highly successful military reconnaissance programs. Likewise, the environmental concerns of the late 1960s and early 1970s helped spawn the Earth Resources Technology Satellite, later known as Landsat. As I will soon explain, these events are now interrelated.

On the classified side of the ledger, the essential goal was to enhance our knowledge of ongoing activities in the Soviet Union, thus removing the uncertainty factor in terms of surprise attack or new military developments capable of altering the geopolitical balance of power. When coupled with the twin pillars of containment and deterrence, information gathered in this manner helped to increase international security and stability.(1)

In addition, arms control agreements that have been achieved to date could in large part be attributed to the success of these systems. Both the United States and the Soviet Union had the confidence to enter into various agreements without compromising their national security strategy and objectives.

In short, classified information systems have proven their worth in the last thirty years. They will continue to be a useful instrument in promoting international security and stability. However, it should also be recognized that the capabilities of classified systems represent the concerns of a certain historical period. They were conceived at the height of the Cold War and military competition between the United States and Soviet Union. This is a thought worth remembering, and I will come back to it in due time.

President Eisenhower's Open Skies concept later emerged in still another form with the launching of ERTS-1(Landsat) in July 1972. Originally envisioned as an experiment to assist with environmental monitoring and crop prediction, we now know that data gathered by Landsat has applications in a number of disciplines, including military intelligence, mineral resources, petroleum exploration, cartography, geographic information systems, land-use mapping, coastal-zone management, hazard assessment, ice mapping, habitat analysis, urban planning, census and many more applications still to be discovered.[2] Moreover, data collected by Landsat is distributed on a nondiscriminatory basis.

Landsat developed an international component as well, in many ways just as large as the one that has evolved with our classified intelligence-gathering systems. During the last 17 years, 13 international ground stations have been built, a sure sign that nations recognize the importance of remotely-sensed data for their economic development needs. Landsat data is also used on an international basis through such programs as the United Nations Environment Program and the Famine Early Warning System. Finally, the success of Landsat has been so great that by the year 2000, it is projected that 24 nations or multinational organizations will launch approximately 48 remote-sensing satellites.[3]

Therefore, as recent history demonstrates, both classified and nonclassified observation systems have been developed in response to various national and international needs and developments. The original Open Skies proposal started a process that continues to emerge today. However, as a nation, and as a planet, we now face the challenge of managing systemic problems that are arguably just as significant as controlling the expansionary tendencies or the Soviet Union of the first signs of environmental decay.

OVERVIEW OF GLOBAL CHANGES

The changes that have transpired on a global basis over the last 30-plus years involve every aspect of society. Understanding the nature, depth and direction of global change will be critical with respect to fashioning a revised Open Skies policy. For the purpose of this paper, I would like to divide these developments into two interrelated groups: changes relating to our inner perceptions of the world in which we live and those major changes that have actually taken place on a global basis.

If you look back over history, advancements in space science and technology have continually reshaped our perceptions of the cosmos and the planet on which we live. The discovery by Copernicus, and later Galileo, that the Sun was the center of the solar system was one such development.

In my lifetime, the one development that transcends all others is the image of the Earth floating in space as taken from an Apollo spacecraft as it circled the Moon. In what was supposed to be a race between the United States and Soviet Union, this unique spin-off has arguably had a greater impact on our perceptions of the Earth and Cosmos since the time of Copernicus and Galileo.

Twenty years later, it is my feeling that civilization is just starting to catch up with the resulting inner paradigm shift, to the newly found responsibilities of living on spaceship Earth. As Chief Seattle stated long before humans travelled to the moon: "The Earth does not belong to man, man belongs to the Earth. All things are connected like the blood that unites us all. Man did not weave the web of life, he is merely a

strand in it. Whatever he does to the web, he does to himself." Or as Joseph Campbell similarly observed: "When you see the Earth from the moon, you don't see any divisions there of nations or states. This might be the symbol for the new mythology to come. That is the country that we are going to be celebrating. Those are the people that we are one with."[4]

Understanding the impact of our changing inner perceptions of the world is vitally important. However, there have been other systemic changes that served to reorder conventional thinking. For starters, the development of nuclear weapons, along with the delivery vehicles to carry them to any point on the globe, fundamentally transformed the dimensions of war. Now we are witnessing the proliferation of nuclear weapons to nonsuperpower states, the proliferation of chemical and biological weapons, and ballistic-missile technology. Although many people are understandably concerned over these developments, it still remains only one aspect of global change.

During the last several decades, we have also witnessed the rise of the global economy. A transition from the era of military competition to one based on economic competition is continually taking place. Today over a trillion dollars will exchange hands on the global marketplace. In that environment, can any nation afford to put vast resources into maintaining a security system based on military power? Has the rise of the global economy been a key factor in reshaping the U.S.-Soviet relationship?

A third aspect of modern-day global change, as well as a principal focus of this conference, is the ongoing developments with respect to our planet's ecosystem. Global warming, acid rain, deforestation, desertification, misuse of natural resources, population and many other factors have all combined to create an uncertain scenario for the future habitat of the planet. Given this perspective, understanding and managing global climate change may represent the ultimate systems challenge.

Finally, we have witnessed the transition from the industrial age to the information age. The information age includes personal computers, fax machines, satellite communications, high-definition television (and whatever comes after HDTV) and remote-sensing satellites, along with the associated value-added technologies. The information revolution may well represent the leading edge for remote-sensing satellites and a revised Open Skies policy.

Satellite images by themselves almost never tell the complete story. Collateral information is often required to make satellite images relevant and we now live in an era where that information, and the means to transmit that information, is readily available. In short, the information age may also be the glue that helps us manage all global changes. After all, information or intelligence must be the basis for new policy development.

POLICY CHOICES FOR OPEN SKIES

Given the scope and variety of global changes that have transpired since 1955, what would be the most appropriate policy choices on which a revised Open Skies process can be based? I would like to suggest that they nominally fall into four categories.

First and foremost, there is the relationship between global environmental change and sustainable economic development. In terms of the environment and economic development, a parallel policy mechanism must be established in the "Mission to Planet Earth" concept. Now there is no doubt that scientific research is vitally important and should, to the greatest extent possible, proceed unburdened by political bias or turmoil. However, as Gro Brundtland, the Prime Minister of Norway recently pointed out:

> "This finite world will have to provide food and energy, and meet the needs of a doubled world population sometime in the next century. It may have to sustain a world economy which is five to ten times larger than the present one....The scientist's chair is now firmly drawn up to the negotiating table, right next to thatof the politician, the corporate manager, the lawyer, the economist and civic leaders."[5]

Since the global environment is a highly interdependent web, and economic development efforts must take into account a number of interrelated factors, what would be the most appropriate way to use information gathered by remote-sensing satellites?

I would like to suggest that remotely-sensed data could play a vital role in augmenting our nation's overseas development assistance efforts. For starters, our nation's efforts have been severely lacking in this arena. As a percentage of GNP, our foreign aid will total three-tenths of one percent for FY 1989.[6] Relative to our national wealth, this is a new low. At the same time, Japan is now the leading nation in terms of overseas development assistance and plans to earmark some $50 billion to be spent from 1988 to 1992.[7]

As we have seen in the past, the mere act of sending economic assistance does not mean development will be sustainable. However, even with present levels of funding, if we couple development assistance with information gathered by satellites, perhaps these resources could be put to better use. When combined with ground and air observations, satellite imagery would serve as a powerful predictive tool and show the relationships between various developments on a local, regional or global basis.

One recent example that illustrates the potential in taking such an approach is the Columbus Discovery Project, an International Space Year initiative to explore and map the Planet. The project will be overseen by the Environmental Research Institute of Michigan and combine maps with Landsat data. The end product will then be given to every developing nation. It is estimated that the cost will be $80 to $100 million over three years, a small fraction of our nation's foreign assistance budget.

The second area in which the Open Skies process could be redirected involves expanded international cooperation. The prospect of 48 satellites being launched in the next decade certainly suggests the time is ripe to consider cooperative endeavors. The trick will be to understand and coordinate the different power requirements of individual nations. For instance, when the European Economic Community consolidates in 1992, there is little doubt that ESA's ERS-01 and the French SPOT series will be of great assistance in providing economic intelligence. The same holds true for Japan and their future remote-sensing capabilities.

Nonetheless, if we start with a goal or mission in which participants have an equal interest, perhaps a process can be initiated that will eventually produce an international or regional satellite monitoring agency. The end product, perhaps several decades down the road, may be based on a number of models, including a synthesis of Intelsat, Inmarsat and even the ISMA that was discussed at the UN in the late 1790's.

Whatever form international cooperation in satellite remote sensing may initially take, I would like to suggest that two factors must be kept in mind. First, the applications of the information gathered should strive to be, as an end goal, multifaceted. Since we live in a world where military, economic and environmental security have been irrevocably joined, can there be any doubt that the international remote-sensing arrangements of the future should have a similar interdependent mission? Finally, an international arrangement should, to the fullest extent, seek to retain the practice of nondiscriminatory access to data. Maintaining this aspect of Open Skies will be equally relevant for scientists and policy planners alike.

The third possibility involves U.S.-Soviet relations. You may recall early on in my paper I suggested that the concerns that propelled our classified systems and Landsat into creation are now interrelated. On

one hand, concerns over the military capabilities of the Soviet Union are still valid. Likewise, concerns about environmental decay are present and present and growing. I would like to suggest that the recent transition in U.S.-Soviet relations, largely in response to the global developments, has now created a need for civilian remote-sensing policies that reflect both concerns. Continuing and improving upon the current relationship may well depend on adopting such an approach.

For example, today's debate on U.S.-Soviet relations is still largely confined to military security questions. Moreover, those proposals to reduce conventional and nuclear weapons are often discussed with little concern as to what type of security system will take the place of the old one both sides seem intent to dismantle.

There is another perspective to consider. The potential to create lasting environmental damage on the part of all nations, but particularly the Soviet Union, the People's Republic of China, and most developing nations, is very real and equally explosive. The Soviet Union, for instance, has the world's largest energy reserves and is the leading producer of oil and gas and contains half the world's accessible coal. Energy also is credited with 52% of all export earnings and petroleum for 60% of hard currency earnings.[8] The potential of the Soviet Union to contribute, I think we can all agree, to global warming is very great.

Therefore, any future Open Skies regime, in relation to the U.S.-Soviet relationship, must address military and environmental questions as interrelated. On the military side, information may be the key to enhancing stability in the face of large conventional, tactical, and strategic nuclear-weapons reductions. In terms of environmental consequences, information will be required to manage resource usage and promote a common objective for both nations. The U.S.-Soviet relationship must be viewed in a greater context than the military one to which we have become accustomed and include environmental concerns, as well as a host of other global developments. Information gathered by civilian satellites can help manage the interrelationship between military and environmental concerns and achieve, after many years, the mutual security regime Representative Brown spoke of in his speech.

The final area that a revised Open Skies policy could address is perhaps the most important: the question of new institutional arrangements. For many years, our classified reconnaissance efforts have been coordinated through the National Photographic Interpretation Center (NPIC). There is no comparable institution in the civilian sphere. While it is true that we have the EROS data center, it remains an archive. In addition, one orbit of a Landsat-type satellite could involve the mission of every government agencyand the jurisdiction of every Congressional committee.

Given that perspective, along with the global challenges we are sure to face in the next decade and beyond, should the existing decentralized arrangements be continued, or should our government, in addition, develop a nonclassified version of NPIC to fully coordinate the applications of information gathered by civilian remote-sensing satellites? I hope you would agree that this step is essential and must be accomplished.

THE ROLE OF H.R. 1574

The possible policy choices on which a revised Open Skies policy can be based are many. Adopting a systems approach to remote sensing is a great challenge, and undoubtedly, it will take a lot of time to figure out all the intricacies. With that knowledge in hand, Congressman Mrazek decided to introduce legislation that would form a national commission to develop a strategy to redirect the ongoing Open Skies process.

The approach that the Congressman has taken can be compared to the decision President Roosevelt made when he formed the Manhattan Project. In that instance, the President knew that developing atomic weaponry would take time. The individuals who were prosecuting World War II were involved in an ongoing crisis. A distinctly separate group was vitally required to develop a new strategic breakthrough.

The same fact of life holds true today as we stand on the verge of another strategic breakthrough in which information will be the next milestone capable of altering the balance of power on a global scale. However, the National Space Council or the National Security Council, both potentially capable of examining what the Congressman's bill proposes, are swamped under by various crises.

The National Space Council first had to address the Landsat funding crisis and then the National Aerospace Plane. I suspect the space station is not far behind. In addition, remote sensing extends beyond space policy. Outer space is only the medium in which it operates. Remote-sensing satellites are a systemic instrument, and policies must be developed that begin to address national and global needs.

Therefore, the Congressman's bill, through the formation of a National Commission, would examine three broad policy questions. First, determine how a revised Open Skies policy could enhance the national security strategy of the United States. Second, examine our civilian remote-sensing program and offer a series of recommendations toward developing a well-coordinated policy. This would include ocean-sensing and atmospheric-sensing satellites, in addition to Landsat-type satellites. Finally, it would study areas in which the sharing of information collected by civilian remote-sensing satellites, cooperatively employed, along with other open information sources, could increase international security and stability.

Clearly, a number of legislative initiatives should be pursued with respect to our civilian remote-sensing program, but the bill represents an approach that has been missing for too long. Global needs dictate that satellite remote sensing must be associated with issues outside the science and technology realm. In addition, the bill has 42 cosponsors from all ideological perspectives. Given the common problems we face as a nation and as a planet, can the Congress afford to be divided on such crucial issues as global climate change and the role information will play in enhancing national and international security? I urge you to carefully examine this legislation. I am sure the Congressman would welcome your support.

CONCLUSION

To quickly review what I have discussed in my paper, I suggested that President Eisenhower started a process thirty years ago that continues today. However, in the 1980's and beyond, national and global needs strongly suggest that the various strands that make up the Open Skies process, particularly in the civil remote-sensing arena, should be redirected or updated.

In short, Open Skies must become an information-age security policy. This policy must address environmental concerns, economic concerns, military concerns, cooperative endeavors, and the old/new dimensions of the U.S.-Soviet relationship. Most importantly, information gathered by satellites must ultimately help people as well as governments understand and manage our changing world. The Open

Skies policy of the 1990s and beyond must, in the words of Chief Seattle, help humankind understand its place in the web of life and ensure that this web is kept in place for future generations.

FOOTNOTES

1. Ray S. Cline, "Nickel and Diming of Landsat," *The Washington Times*, March 13, 1989.
2. Murray Felsher, "Civilian Satellite Remote Sensing: At the Crossroads," Remarks Prepared for Delivery, the American Society for Photogrammetry and Remote Sensing, April 3, 1989.
3. John L. McLucas, "Mission to Planet Earth," The Wernher von Braun Memorial Lecture for 1989, January 26, 1989, p. 10.
4. Joseph Campbell, "The Power of Myth," An Interview with Bill Moyers, pps. 32-3.
5. Mrs. Gro Harlem Brundtland, "Global Change and Our Common Future," The Benjamin Franklin Lecture, Washington, D.C. May 2, 1989, pps. 1 and 3.
6. CRS Report for Congress by Stanley J. Heginbotham, "An Overview of U.S. Foreign Aid Programs," Revised and Updated by Larry Q. Nowels, March 30, 1988, p. 13.
7. John Stremlau, "Security for Development in a Post-Bipolar World," June 15, 1989 Draft, pps. 27-28.
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ECONOMIC AND POLITICAL IMPLICATIONS OF CLIMATE CHANGE

by

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INTRODUCTION AND BACKGROUND

There is now virtually unanimous agreement in the climatology community that a future climate change as a result of human activities is inevitable and that it is undoubtedly already taking place. There has been an 0.6 to 0.8 K increase in the global average temperature in the past 100 years, and the most likely explanation for this trend is the increase in concentration of certain infrared-absorbing gases in the atmosphere—the so-called "greenhouse gases." The most important of these greenhouse gases up to now is carbon dioxide, but methane, nitrous oxide, the chlorofluorocarbons (CFCs), and others may become important contributors to the warming in the decades ahead.

The increase in these trace gases in the atmosphere has been due to human activity, primarily the burning of fossil fuels and (to a lesser degree) certain agricultural practices. There is no doubt about the reality of this increase in the atmosphere, since the concentrations of these gases has been monitored for many years, and it has even been possible to extend the record back in time by analysis of atmospheric samples captured and locked in the ice sheets of Greenland and the Antarctic—samples whose age extends back to a period long before the intervention of mankind.

If we wonder how fast this buildup of the greenhouse gases will take place in the future, we must ask what the future course of energy use will be. Will we continue to increase the rate of use of fossil fuels at 2% per year? Will we learn to use energy more efficiently and thereby decrease our consumption? Will we resort to nonfossil renewable energy sources or nuclear energy that do not produce carbon dioxide? The largest increase recently in fossil-fuel use has been in the developing countries, and we may ask: can they afford to continue this expansion into the next Century? A related question of even more basic importance is: will they be able to bring their population explosion under control?

These are obviously important questions for many reasons, and other papers at this conference will touch on some of the answers. Since the greenhouse gases are responsible for the future warming, it is difficult to put a time scale on the rate of climate change without knowing what the future demand for fossil fuels will be. In other words, the global climate system is being forced by a new factor that has never been present to the extent that it is now. It has been aptly said (Revelle and Suess, 1957) that mankind is conducting a geophysical experiment on the climate of Planet Earth.

This idea is not a new one (Revelle, 1985; Kellogg, 1987). At the end of the 19th century two scientists made the connection between our use of fossil fuels and the climate. In Sweden the Nobel Laureate chemist Svante Arrhenius made a remarkable set of calculations showing that a doubling of atmospheric carbon dioxide would warm the world by 5 to 6 C and that the warming would probably be larger at the poles than at the equator. This is in fair agreement with current estimates, based on much better information and the use of computer models.

The American geophysicist-turned-college-president Thomas C. Chamberlin (he was president of the University of Wisconsin) extended the Arrhenius theory to develop a theory of ice ages based on changes in atmospheric carbon dioxide. This too was a remarkable leap forward in linking the atmosphere, climate changes, and geologic processes, which is now becoming a major thrust in the international Global Change research program.

Why did the insights gained almost 100 years ago attract so little attention until quite recently? The idea that mankind could actually modify the climate of the enormous climate system consisting of the oceans, the atmosphere, the land, the ice sheets of the poles, the biosphere, and the sun was generally regarded as something very far in the future—a kind of science fiction. It was not until the early 1970s that this idea gained more general credence (WMO, 1979; Kellogg, 1987). Since then it has gradually been accepted as a reality.

One of the reasons for downplaying mankind's influence on climate must have been our failure to recognize the massive scale of industrial activity and the enormous expansion of the use of fossil fuels of all kinds in the early part of the 20th century. From the turn of the century to 1973, the use of fossil fuel increased at a rate of about 4% per year (a doubling time of a little over 15 years!), and since then it has continued to increase at about 2% per year. Every year we are now contributing roughly 6 gigatons of carbon in the form of carbon dioxide to the atmosphere, and as a result, the concentration of this gas is increasing by about 0.3% per year. Its concentration of 350 parts per million is about 30 above its pre-industrial value (e.g., Ramanathan, 1988).

Methane, another greenhouse gas, is increasing at over 1% per year, and will rival carbon dioxide in importance early in the next century if this trend continues. Sources of methane are not as clear as those of carbon dioxide, but release of natural gas, plus bacterial production in rice paddies and the stomachs of ruminants and termites, are all contributing factors. At the same time, there is good reason to suspect that the photochemical removal of methane is slowing down, and this could also contribute to its observed increase.

Our climate models tell us that a doubling of greenhouse-gas concentration will raise the average global temperature by 3 to 4 C, with (as pointed out by Arrhenius) two or three times larger increases in the Arctic and the Antarctic (NRC, 1983; 1987; Villach/Bellagio Workshops, 1987). When will this doubling over the pre-industrial concentration occur?

As pointed out already, the answer does not lie entirely in the realm of geophysics, but we can reasonably bracket the possibilities by assuming as a "high" rate of increase a continuation of the current trends, and as a "low" rate of increase a leveling off and a return to the present rates of fossil fuel use, methane production, CFC production, etc., in 50 years. These two extremes have been used in drawing the future temperature curves shown in Figure 1.

In Figure 1 we see just one dimension of the climate change ahead. It is of little use to tell a political or industrial leader or a farmer what the global average temperature change will be. He or she wants to know what will happen here (wherever "here" happens to be), and moreover, temperature is not the only thing of interest. Rainfall and soil moisture are actually more important than temperature in determining where things can grow.

In the next section we will develop that last theme, and then briefly discuss some of the implications of climate change to human affairs. In the last section a few suggestions for action to delay and prepare for the change are outlined. Many of these suggestions are echoed in other presentations at this Conference, and with applications to more specific regions and economic sectors.

REGIONAL SCENARIOS

Many climatologists are doubtful that it is possible at this point to develop regional scenarios of future climate change, except in the most general terms. For example, it is conceded that the temperature increase in the polar regions, especially in the Arctic, will be several times larger than in the equatorial zone, but beyond that the details are obscure. And when it comes to changes in precipitation, it is sometimes claimed that there are far too many difficulties (e.g., NRC, 1983; Villach/Bellagio, 1987).

We would not dispute the fact that there are indeed difficulties in developing regional scenarios, but their importance in climate-impact studies is so great that we feel it necessary to try. There are at least three ways to approach the regional scenarios: (a) experiments with climate models, in which a model is run with present boundary condition and then with doubled or quadrupled carbon dioxide, and the differences between the two runs can then be plotted on a map (e.g., Schlesinger and Mitchell, 1987); (b) an examination of the anomalous patterns of temperature and rainfall that prevailed during unusually warm years or sequences of years in the Arctic (e.g., Jager and Kellogg, 1983); (c) deductions about the climate during warmer periods in the more distant past, notably the Altithermal Period of about 4500 to 8000 years ago and the last Interglacial Period of about 120 000 years ago, based on pollen analyses and former distributions of trees and plants, heights of lakes and rivers, glacier advances or retreats, and so forth (e.g., Delcourt et al., 1983; Street-Perrott and Harrison, 1985; COHMAP Members, 1988). All of these approaches have been taken.

However, none of the three can be relied on by itself with a great deal of confidence, for the following reasons. The climate models, although they have advanced enormously in the past several years, are still primitive and oversimplified compared to the real climate system, and (as we will show presently) different models do not always agree with each other. The situation during anomalously warm years in the Arctic may be just a transient condition and therefore would not be a good analog for a gradually warming planet. Finally, it is argued that the Altithermal Period and other more remote warm periods were warmer than now because of the different distribution of solar radiation in winter and summer, not necessarily because of the greenhouse effect.

The counter arguments are, briefly, that: (a) the climate models are the best we have now, and in fact one can see agreement between them in certain important areas of interest; (b) in both the anomalous-year approach and that of the Altithermal, we are dealing with a situation in which the equator-to-pole temperature gradient was less than now, so the large-scale general circulation patterns could be representative of that under an increased greenhouse effect—even though the causes may be different; (c) in the case of the Altithermal, we can not only deduce a different prevailing climate, but we can also study the way natural ecosystems changed their distributions in response to an altered climate.

Keeping all these caveats and positive arguments in mind, let us briefly look at the lessons to be learned about the future climate. We will emphasize North America, but of course the same arguments apply elsewhere. First, consider Figures 2 and 3, which summarize the results of five climate model experiments with different state-of-the-art models but all using the equilibrium approach (Kellogg and Zhao, 1988). The area shown is North America, although the models are truly global, and the seasons are winter and summer. These climate models all incorporate sophisticated general circulation models (GCMs) governing the atmosphere; the atmosphere is coupled to the land with its mountain ranges and (in one case) varying soil type; and the oceans are modeled assuming an upper mixed layer that has the right heat capacity to give a realistic seasonal change of surface temperature. (In two cases, the horizontal transport of heat by the oceans was taken into account in a rough way.) Most pertinent in the present context is

the fact that all five of the models calculated the distribution of soil moisture and how it changed with the seasons. Many more details of these models and how the experiments were run are given in the referenced report. Figure 2 shows that, with a doubled concentration of carbon dioxide, in winter there is remarkably good agreement on an increase in soil moisture in most of Canada and northern United States, and they agree on a decrease in central Mexico. However, the northern result is probably complicated by the fact that the land in winter is generally covered with snow and the ground is frozen, so soil moisture is difficult to estimate.

Figure 3, for summer, shows poorer agreement between the five models, but the consensus is a drying out over most of the continent, and some increase in soil moisture along the Gulf Coast and the West Coast of the United States. The only places where there is unanimous agreement on the summertime drying trend is a small area in the High Plains and in central Mexico.

As pointed out earlier, it would probably be a mistake to accept these climate-model results at face value without some corroboration from "the real thing." Figure 4 shows the distribution of precipitation anomalies for the average of the 10 warmest Arctic summers and falls between 1930 and 1978 (Jager and Kellogg, 1983). Again we see evidence for decreased precipitation in the middle of the continent, a tendency that would definitely lead to less soil moisture when combined with a warming. And again there is the suggestion of increased moisture along the Gulf Coast and the West Coast of the United States, and here in summer that change extends northward along the west coast of Canada and into Alaska.

The same analysis for winter (not shown here) shows increased precipitation in northern Canada and decreased precipitation in the southeastern United States, in agreement with the models results, but in the middle of the continent one cannot claim agreement.

What does the Altithermal Period tell us about the climate of a warmer North America? Most of our evidence about the climate of 4000 to 8000 years ago comes from the distributions of pollen in soils, bogs, and lake beds, and such analyses allow one to deduce what was growing at each site as a function of time. The picture is fairly complex, especially in the west and southwest, but there definitely seems to have been a drier climate in the midwestern U.S. (the present wheat and corn belt). During the warm Altithermal, for example, the prairie grass extended across Illinois and into Indiana, but by the time of the arrival of Europeans there was a cooler and wetter climate, and forests had gradually pushed the grassland back to roughly the Mississippi. This change in the moisture regime must have corresponded to summertime, the growing season. At the same time, along the Gulf Coast of the U.S. there is no evidence of a drier climate during the Altithermal, and the forests were very much as they were found 200 years ago (before the arrival of Europeans with their axes) (Delcourt et al, 1985), again in general agreement with the climate model experiments.

In summary, there does seem to be enough agreement on certain aspects of the changes in moisture to be expected as the world grows warmer so that we can (and should) begin to take these changes into account in our planning for the future. In some parts of North America we cannot see a consistent pattern emerging yet, but in the Great Plains and the Corn Belt in summer, a drying trend is indicated by all the approaches. By the same token, little change in soil moisture may take place along the Gulf Coast and the West Coast in summer—it might even increase. It seems that the evidence is still inconclusive in the area of the Rockies, the Great Basin, and the Southwest generally, which is unfortunate in view of the fact that these areas are already marginal for agriculture and water resources are therefore crucial.

Are the mid-western droughts in the United States in 1988 (and to a lesser degree in 1989) an indication that the greenhouse effect is already here? Are the floods in Bangladesh also a part of the changing greenhouse pattern? These are questions that are being asked with increasing insistency these days. It is

fair to say that these events of the past summers are entirely consistent with the kind of situations that we can expect to see more frequently as the world grows warmer. They do not prove, by themselves, that the greenhouse warming is already with us, but we should heed the implied warnings.

SOME IMPLICATIONS OF CLIMATE CHANGE

There are obviously many kinds of impacts of a global climate change, but the most obvious are the effects on agriculture, forestry, and range management (Parry et al, 1987). These are the activities that feed and clothe the world, and grain is the largest single international trade commodity after petroleum. Thus, climate change may strike at the very heart of nations and their economic well-being.

In the previous section a rough and tentative climate scenario was discussed, with emphasis on shifts in rainfall and soil moisture. Figure 5 is a map that represents the possible worldwide shifts of soil moisture as the earth grows warmer due to the greenhouse effect. To put these shifts into more meaningful terms, consider what they mean to certain kinds of food production (Kellogg and Schware, 1981). For example, in 1979 the Soviet Union produced about 25% of the world's wheat, and the United States a bit over 10%, according to the Food and Agriculture Organization. In both of these countries the wheat-growing regions are just those predicted to have a decrease in soil moisture—they may be both hotter and drier. By contrast, the wheat-growing regions of China and India, which together produced nearly 20% of the world's wheat, are mostly in the areas due to have a more favorable climate (according to our scenario).

About 50% of the world's corn production is by the United States, mostly in the "corn belt," and this is a region due to become drier. The next largest producer of corn is China, over 10 , and its corn belt is due to become wetter for the most part. About 55% of the world's rice, whose worldwide production is second only to wheat, is grown in China and India, and these are expected to continue to have favorable climates—perhaps even improved climates, allowing two crops per year in parts that are now too cool for that.

These examples demonstrate how the new climate of a warmer world could shift the balance of trade in food. It is too early to put numbers into the equation that defines this balance, but we should certainly be prepared for it.

There are, of course many countries in the subtropics that are not so much concerned with international trade as with survival. This is most true of many countries in North Africa, and, among others, northeast Brazil and northwest India share in the problem of how to feed their people. There is some evidence, primarily from the Altithermal Period, that a warmer Earth will be more favorable for many of these areas. The Sahara was not a desert 5000 years ago, and people grazed their cattle in what was then a savanna. In the Rajastan Desert of northwest India there are ruins of sizeable cities now buried in sand. We can hope for the sake of those countries that the greenhouse effect will turn the clock back to a more favorable climate in the subtropics.

Although scientists in the industrial world seem to be increasingly concerned with global change, to date there has been relatively little evidence that the leaders of governments and industry are taking it into account in their planning. There are, however, at least four economic sectors that must plan on a long time horizon, and their planners are beginning to listen. These sectors are (a) the energy generation and distribution industry (which is the primary cause of the climate change and, at the same time, affected by it), (b) the management of large water systems (dams, irrigation canals, etc.), (c) the forest-products industry (it takes 50 years or more for a plantation of trees to reach the size for lumber), and (d) those concerned

with the disposition of nuclear waste (to be kept safely for 10 000 years or more). We should also mention the grave concern over the problem of future sea-level rise, which will affect shoreline communities the world over.

Returning to the forest-products industry, there have been several meetings of those concerned with this sector in the past few years, especially in the southeastern United States (Meo, 1987). A major source of income for the states along the Gulf Coast is the growing and harvesting of loblolly pines, a species well adapted to the climate there and very fast growing. These trees cannot withstand drought, particularly when young, and one new plantation of tens of thousands of acres in southeastern Oklahoma of the Weyerhauser Company lost some 35% of its new plantings in the hot dry summer of 1980. Is this the kind of event that will occur there more frequently in the future?

Another sector that will be affected by a global warming is the one concerned with energy generation and distribution in all its forms. As pointed out already, it is mankind's hunger for increasing energy that is mostly responsible for the climate change. And the patterns of supply and demand will change with the coming climate. One obvious example is the expected decrease in requirements for space heating in winter but an increase in demand in summer for air conditioning, especially for electrical power. Will we see progressively more cases of summertime grid network overload and "brownouts" in the United States? Could such a trend be countered by increasing reliance on solar energy?

Obviously, this discussion has only scratched the surface of the enormous range of impacts that climate change will have on mankind. These examples will serve to suggest many more. The important lesson is that any such change will force readjustments. Some of these will be pleasant, and more will be difficult. It is the obligation of climatologists and social scientists, working together with the leaders of government, industry, and agriculture, to sort out as best they can what these readjustments will be. To do this adequately, more detailed scenarios of the climate to be expected in the future must be developed, including the probability of extreme anomalies in the weather.

We have not emphasized the much publicized likelihood that sea level will rise as the world grows warmer. This will be due to the water of the ocean expanding as it warms, and to a lesser degree the melting of glaciers on land. A widely quoted estimate by a respected committee of the NRC's Polar Research Board (NRC, 1985) is that sea level may be about 0.5 m higher by the middle of the next century—and it has risen about 0.2 m in this century. Eventually, at least several centuries from now, the great ice sheets of Greenland and the Antarctic could shrink or in part slide into the ocean, and the latter could cause several meters of sea level rise. However, this does not seem to be of as much concern as the more immediate environmental crises that we have been discussing (NRC, 1985; Radok et al., 1987).

SOME POSITIVE STEPS TO BE TAKEN

Several prestigious international and national bodies have concluded that the problems posed by future global climate change, together with other human influences on the environment, are second in importance only to the danger of nuclear war. The reasons for this conclusion are clear from what has already been said here. The rate of this global change is expected to be faster and the magnitude greater than any environmental change in the long history of mankind. The bottom line seems to be that, where the climate is concerned, it is no longer smart to say "business as usual."

Already there have been a number of well-publicized statements dealing with the general problem and suggesting what measures can be taken (WMO, 1979; NRC, 1983; 1987; Villach/Bellagio, 1987; Climate

Institute, 1989; NRDC, 1989). All invariably call for more research on the climate system so that we can make better predictions of the future. Without such predictions it is hard to know what measures to take to mitigate the impacts of climate change, and these predictions must be detailed enough so that the regional changes can be appreciated. In any case, the countries of the world must try to prepare for the change—this is a point that few would argue with. This is termed "the Genesis Strategy" in Figure 6, after the story of Joseph in Egypt and the seven years of plenty followed by seven years of famine.

There are also those who sound a call for action to avert the change, considering the damage that it will do to our natural ecosystems as well as to society as "unacceptable." This school of thought is represented by the left branch of the decision tree in Figure 6. Their arguments and their rhetoric have a certain appeal. Unfortunately, however, just what steps the leaders of the world can be realistically expected to take is still far from clear. Furthermore, at what level of climate change does the situation become "unacceptable?" Remember that some countries will see themselves as benefitting from the new climate.

The global changes that we see taking place are due to a variety of mankind's activities, including the cutting down of tropical rain forests, the poisoning of air and water, creating deserts by bad land use in marginal areas, and most of all, by our insatiable demand for energy. (These are all ultimately related to the apparently inexorable increase of the world's population.) We are meeting this demand for more energy by taking fossil fuel out of the ground and burning it, thereby increasing the carbon-dioxide concentration. At the same time related activities are adding other greenhouse gases to the atmosphere, as already pointed out. This is the cause of the global warming that is already taking place.

Thus, if the climate change is considered "unacceptable," then we must stop burning fossil fuels—or at least greatly reduce their use. We may hope that alternatives to fossil fuel will turn out to be economically attractive and therefore adopted, these alternatives being renewable energy from the sun, geothermal energy, and nuclear energy. But so far there has not been a widespread conversion, and the worldwide use of fossil fuels continues to increase at about 2% per year. Most of the increase is due to expanding demands in the Third World, whereas the industrialized countries are finding that greater efficiency in the use of energy is the best course. (These wealthier countries are also experiencing some leveling off in their populations.) In regard to conservation of energy, the United States has the largest per capita energy consumption in the world, and therefore has a long way to go to catch up with the other countries. Such an effort is obviously to be encouraged, but by itself the U.S. cannot make a large impact on fossil-fuel consumption, since it only accounts for about 25 percent of the worldwide use, and this fraction is lessening each year.

Can we persuade the world to phase out the use of fossil fuels? It will not be easy. Consider the enormous vested interests in production and use of fossil fuels. Consider that some countries will see themselves as benefitting from the climate change (whether true or not) and would not agree to relinquishing the use of this most convenient source of energy. Consider that scientists are still divided on the subject of what to expect and how fast the change will occur. In the face of all these considerations, it will be unlikely, in my opinion, that the political leaders of the world will be willing to enter into agreements to limit fossil-fuel use—at least for many decades, until the climate change has progressed much further and its costs (and benefits, if any) are clear to everyone.

On the other hand, the list of measures that could be taken to mitigate the adverse impacts of climate change are all things that make sense anyway. They include better management of agricultural and industrial water resources, the development of adaptable crops, protecting topsoil from erosion, reforestation, and so forth (Kellogg and Schware, 1981; 1982). Notice that such measures, to be effective, must be adopted at the local or regional level. Each part of the world will have its special problems and solutions.

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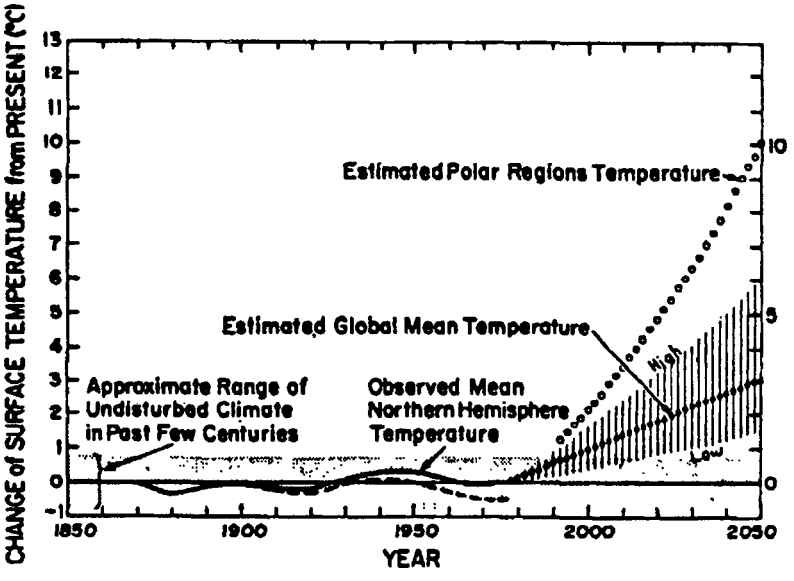


Figure 1. Past and future globally averaged temperature and estimated polar regions temperature. The dashed line indicates the temperature record that might have taken place if there had not been greehnouse gases added to the atmosphere. The vertical bars indicate the range between a "high" and "low" scenario of fossil fuel use (see text). This temperature scenario assumes that a doubling of the greenhouse gases will occur about 2050 for the dotted "estimated temperature" curve.

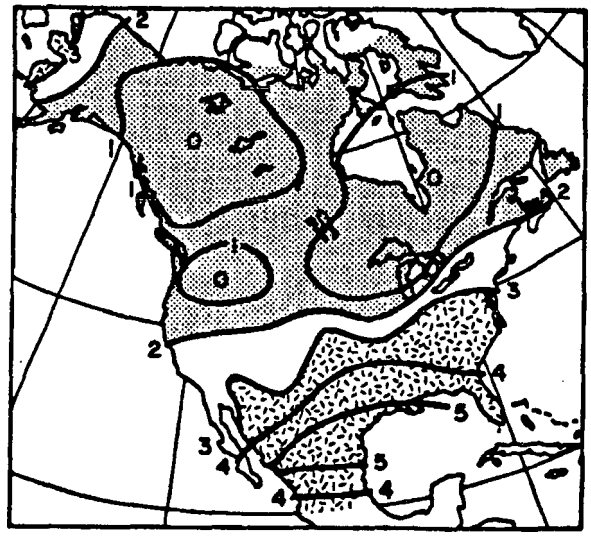


Figure 2. Map of North America showing the degree of agreement among the five climate models on the direction of the soil moisture change in winter with a doubling of atmospheric carbon dioxide concentration. Areas shaded with hen-scratches show where three or more of the models agreed on a decrease of soil moisture; areas stippled with small dots show where three or more agreed on an increase. (Source: Kellogg and Zhao, 1988)

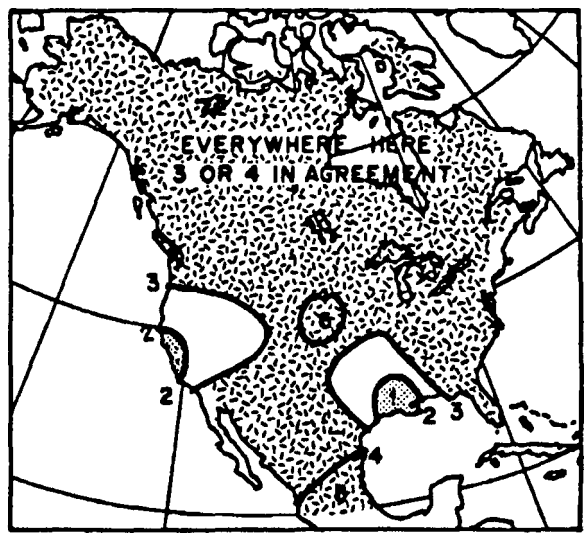


Figure 3. Same as Figure 2, for summer.

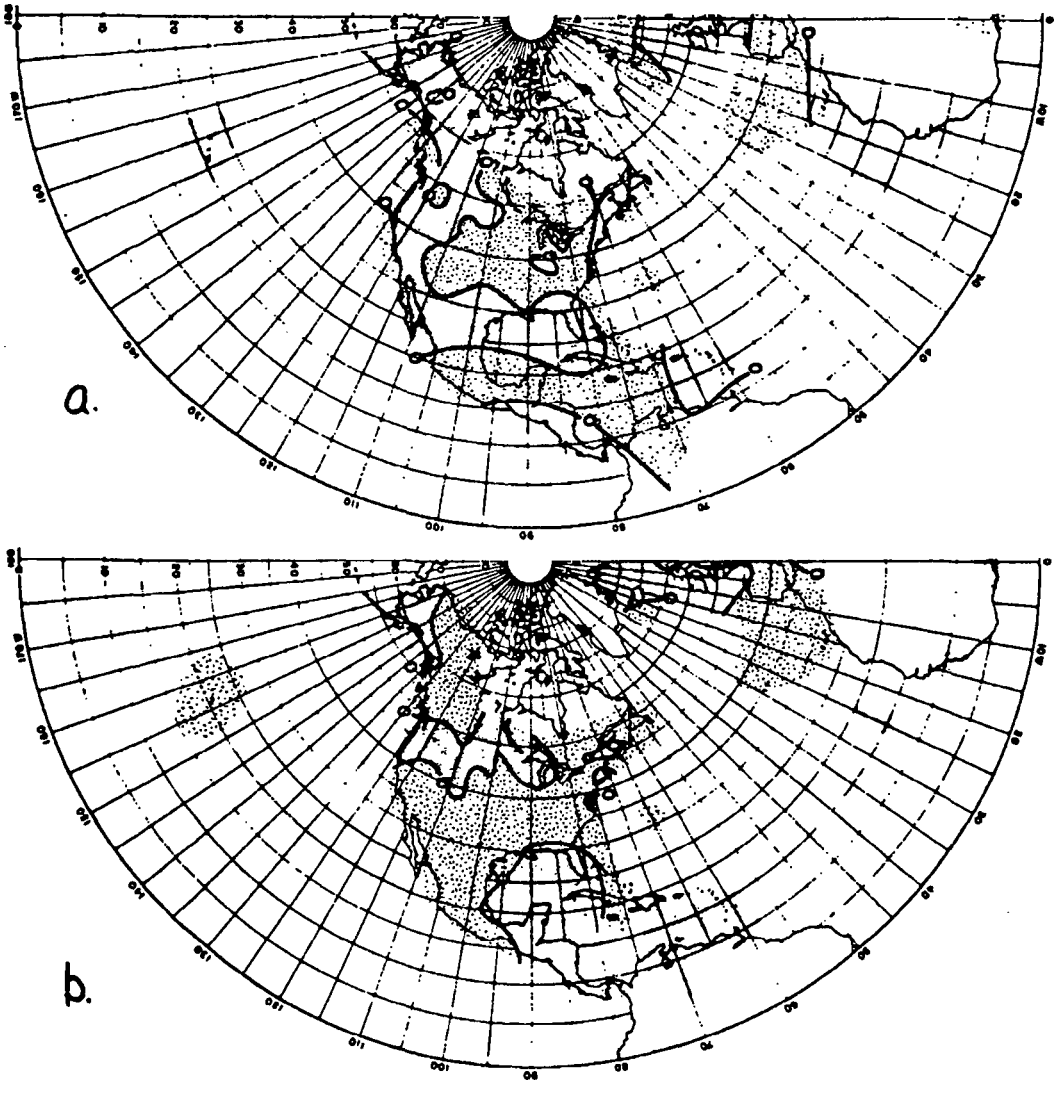


Figure 4. Precipitation anomalies for the average of the 10 warmest Arctic summers (a) and autumns (b), i.e., difference between the warm years and the residual average for the period 1931-1978. Stippled areas have more precipitation, hen-scratched areas have less. (Source: Jäger and Kellogg, 1983)

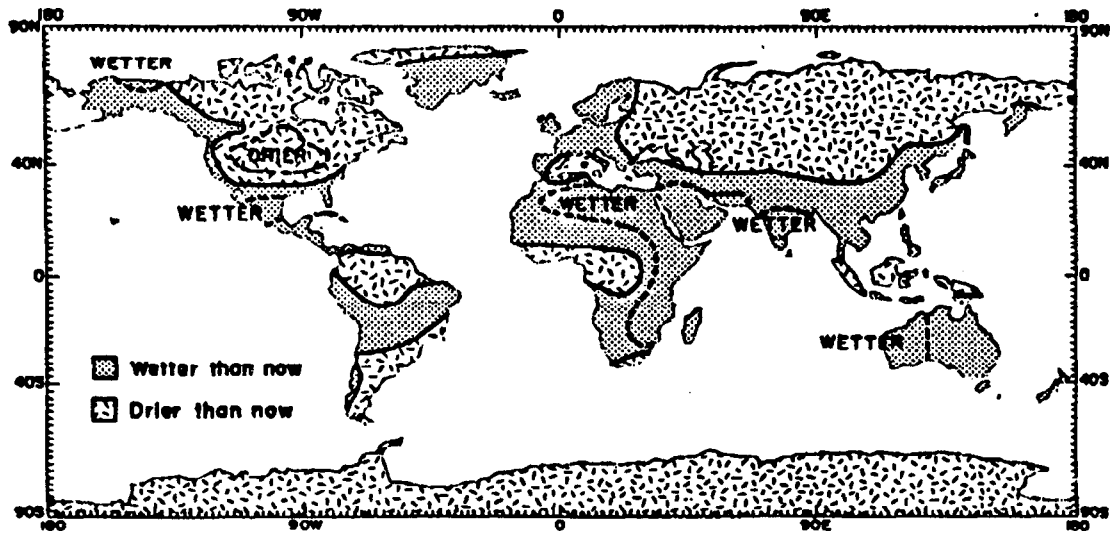


Figure 5. Areas of the world where it may become either wetter (stippled) or drier (hen-scratched) as the planet grows warmer. In regions surrounded by dashed lines and labeled the prediction is more likely to verify.

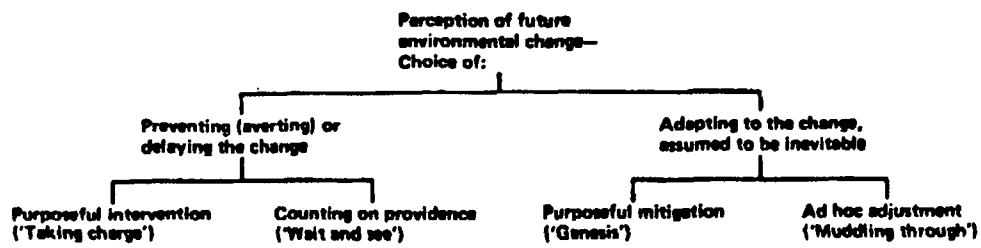


Figure 6. A decision tree showing the range of choices that could, in principle, be made in order to cope with climate change. The actions on the left would presumably have to be taken on a worldwide basis to be effective (see text), but those on the right can be taken at any level of society.

COOPERATIVE, MULTI-DISCIPLINARY PROBLEM SOLVING FOR CHEMICAL ACCIDENTS

by

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CHEMICAL ACCIDENTS—THE PROBLEM

The manufacture, transportation, and use of hazardous chemicals is increasing worldwide and with this increase also comes an increase in the frequency of serious chemical accidents. In addition, increasing population and population expansion around existing chemical facilities means that the consequences of these accidents are becoming more severe.

In the twenty-four member countries of the Organization for Economic Cooperation and Development (OECD), which includes most of the chemical manufacturers, over 200 chemical accidents causing significant damage to human health, environment, or property occur each year. In the U.S. alone, EPA has recorded at least 6928 accidents with acutely toxic chemicals in the last five years. These accidents killed 135 and injured nearly 1500 people.

Compared to other industries, the chemical industry had an excellent safety record. It ranked second safest of 42 industries polled in 1986 according to National Safety Council statistics. Yet 44% of those responding to a recent Chemical Engineering (October 10, 1988) survey said their plants have had a major accident within the last five years, and 70% of these think that a similar accident could happen again. The tragic methyl isocyanate release in December 1984 at Bhopal, India, where approximately 3000 people died and 50 000 were permanently injured, has shown us that the consequences of an accidental chemical release can be unacceptably severe. A list of 10 major chemical accidents that have occurred in the last 14 years is given in Table 1. At least 30 principal accidents (those having at least 100 persons dead, or 35 000 evacuated, or 70 000 without drinking water) involving hazardous substances have occurred between 1974 and 1988. The number of such accidents has diminished in OECD countries since 1983 but has increased rapidly in the developing nations.

The chemicals of concern, according to OECD analysis, include petrochemicals and explosives, chlorine and other toxic chemicals and chemical products, butane, and propane. Hazardous chemicals with a potential for creation of large, toxic airborne clouds include ammonia, chlorine, hydrogen fluoride, hydrogen cyanide, hydrogen sulfide, liquefied natural gas, liquefied petroleum gas, phosgene, sulfur dioxide, sulfuric acid, and others. Those chemicals that are stored or used under pressure at temperatures above their boiling point create the most severe hazard because they can flash to aerosol and vapor upon release and create a heavy, cold cloud full of small droplets that remain airborne and travel long distances before dispersing.

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Recent Chemical Accidents Worldwide

			Deaths	Injuries	Evacuations
Flixborough	UK	1974	28	29	3 000
Beek	Netherlands	1975	14	104	—
Seveso	Italy	1976	—	193	730
Los Alfagues	Spain	1978	216	200	—
Mississauaga	Canada	1979	—	8	220 000
Tacoa	Venezula	1982	145	1 000	40 000
Cubatao	Brazil	1984	508	—	—
Mexico City	Mexico	1984	452	4 248	31,000
Bhopal	India	1984	2 800	50 000	200 000
Institute, WV	U.S.	1985	—	140	—

CHEMICAL ACCIDENTS—THE CAUSES

It has been well established that human error is the principal cause of chemical accidents, particularly large catastrophic accidents that involve defeat of engineered and operational safeguards. The Bhopal accident was so severe because of the violation or defeat of at least ten procedures or engineered safeguards. Whether this was intentional sabotage or not, it is an example of extreme management and regulatory inadequacy. Sloppy maintenance, poor safety practices, inadequate operator training and supervision, and other human errors, in addition to design flaws, hopelessly compromised a many-layered safety system. Recent studies have shown similarities between the human factor deficiencies that led to Bhopal and those that led to the Chernobyl and Three Mile Island nuclear accidents. Analysts of these accidents warn that the world has not learned its lesson and that millions of people remain in jeopardy from other potential accidents. Lack of knowledge, poor training, poor operational practice, and inadequate management create a climate conducive to human error. At Bhopal, these problems allowed a series of compromises and failure of virtually all safety systems designed to prevent release. Lack of advance planning and failure of all emergency response systems then meant that the consequences of the accident would be severe and could not be mitigated once it began.

Cultural differences also play a role in accidents. The most obvious is the problem with complex technologies in developing countries. All too often knowledgeable persons and specialized equipment from the developed countries are not allowed in favor of developing a local capability. All too often the careful "safety mentality" and high level of general technical sophistication present in industrialized countries are also not present. Chemical accidents are declining in OECD countries but are increasing worldwide because of increases in developing countries. OECD predicts future serious accidents are more likely to occur in the developing countries.

There are also "cultural" differences between industries. The chemical industry, as a whole, has an excellent safety record and has developed a careful, sophisticated, multilayered safety "culture" that generally works well. The petroleum refining industry does not have as good a safety record as the chemical industry and has a different "culture." Recently, an alkylation process that uses large quantities of anhydrous hydrofluoric acid (HF), a very dangerous and toxic chemical, has come into widespread use

within the petroleum refining industry. The question that needs to be asked is: will the refining industry be able to adapt its "culture" to deal successfully with the increased hazard caused by this new chemical?

A similar situation existed when nuclear power was commercialized. It is my opinion that the "culture" of the electric utility industry was not sufficiently sophisticated or safety conscious to deal with the increased hazard that nuclear power brought with it. Studies of the Three Mile Island accident have supported this conclusion.

Equipment failure and design flaws cannot be ignored even though they are much less important than human error. The Flixborough cyclohexane explosion was caused by an unauthorized piping repair that failed under normal operating conditions. At Bhopal, the emergency relief system was not designed to handle run-away reactions; consequently, there would have been severe problems even if the flare and scrubber systems had been operational. A recent American Institute of Chemical Engineers (AIChE) study by Design Institute for Emergency Relief Systems (DIERS) has shown that many emergency relief systems are not adequate for two-phase releases and consequently would not handle many run-away reactions. About half of the responders to the Chemical Engineering survey stated that incidents at their plants were caused by inadequate inspection and maintenance of the various process safety devices.

Careless zoning, resulting in inadequate buffer zones between hazardous chemicals and population, also contributes to loss of life during an accidental release. This was a major contributor to the large number of fatalities resulting from the Mexico City (1984) liquefied petroleum gas (LPG) accident and also at Bhopal. In both cases, large populations of poor people lived in slums constructed next to the plant after it was built. Also, in both cases, large numbers of fatalities occurred among people in these areas. In the U.S., typically, zoning laws are lax, so that in many urban areas, dense residential housing and shopping centers are being built within the potential danger zones for toxic clouds and explosions that could result from accidental chemical releases.

CHEMICAL ACCIDENTS—THE RESPONSE

The Public

In a very general way, studies have shown that the public is losing confidence in science and technology. Major accidents, such as the Chernobyl nuclear accident and the Bhopal chemical accident, help to further erode that confidence. Confidence building through technology is possible if the same sophisticated and advanced technology that is currently working to produce products, knowledge, and energy for our advanced industrial cultures can also be used to help protect us from technology when something goes wrong. Better yet, would be using advanced technology to keep accidents from occurring in the first place. Industry has and does emphasize prevention.

The National Science Board reports that 80 percent of the public believes that scientists work for the good of humanity, but 55 percent believe that their knowledge gives scientists a power that makes them dangerous. Putting equivalent power to work protecting public health and welfare would help to change that perception. It is important to remember that it is not necessarily the actual safety record that matters but rather the public perception of whether or not there is a problem.

The Industry

The chemical industry has taken the initiative in several areas. Shortly after Bhopal, the American Institute of Chemical Engineers (AIChE) created the Center for Chemical Process Safety (CCPS), which is chartered to improve safety of manufacturing and handling chemicals through intensified focus on engineering practices. To this end, CCPS has created a small research program oriented toward establishing, publishing, and advancing engineering practices for prevention and mitigation of catastrophic incidents involving toxic or reactive materials. Their objective is to avoid a recurrence of a catastrophic chemical accident like the one in Bhopal. Prior to creation of CCPS, AIChE sponsored the DIERS work investigating the adequacy of relief valves for two-phase flows from run-away chemical reactions. The Chemical Manufacturers Association (CMA) has established its Community Awareness and Emergency Response (CAER) program. This program outlines steps to take in developing and implementing an emergency on-site response plan.

Industry trade associations also have been active in improving safety within their industries. The Fertilizer Institute (TFI) helped sponsor atmospheric dispersion experiments with large releases of ammonia; Gas Research Institute (GRI) helped sponsor various liquefied natural gas (LNG) safety research projects over the last ten years; The American Petroleum Institute (API) has sponsored numerous research projects related to the safe use of chemicals within the petroleum refining industry. Some of the most recent and most ambitious work has occurred under the sponsorship of an ad hoc group of approximately twenty users and manufacturers of anhydrous hydrofluoric acid (HF). Amoco took the lead in 1986 with some HF atmospheric-dispersion and water-spray mitigation experiments. Based on the results of those experiments, work on water-spray mitigation, vapor barriers, and improved atmospheric-dispersion modeling has been conducted. The water-spray mitigation project was very elaborate and extensive, involving construction of a large wind tunnel dedicated to releasing hazardous chemicals, extensive instrumentation, and 87 test releases of HF.

The U.S. Government

Prior to Bhopal, a number of laws affected the chemical industry. Chief among these were:

- Occupational Safety and Health Act,
- Clean Air Act,
- Clean Water Act,
- Toxic Substances Control Act, and
- Hazardous Materials Transportation Act.

None of these laws addressed the catastrophic release of a large amount of hazardous material. There was, however, the National Response Team, which consisted of 14 Federal agencies, and the National Response Center, operated by the U.S. Coast Guard, available to deal with catastrophic accidental releases. There were also several research programs that were working in this area to provide information needed by industry and the Federal agencies. A joint effort between the U.S. Department of Energy (DOE), the U.S. Department of Transportation (DOT), and GRI had begun to address concerns over large-scale releases of LNG, and a long-standing program within the U.S. Coast Guard was sponsoring work with ammonia in collaboration with TFI (begun in 1978). In 1982, the process of shutting down these programs was

begun by both agencies. At the same time, the U.S. Congress was pushing the Federal agencies to do more research and had DOE build an elaborate spill test facility at the Nevada Test Site.

After Bhopal, the U.S. Congress passed the Emergency Planning and Community Right-to-Know Act (Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA)), which directed EPA to establish:

- local emergency planning committees (LEPC),
- emergency response plans,
- list of hazardous substances and reportable quantities,
- public right to information,
- material safety data sheets (MSDS), and
- annual chemical inventory reporting.

Essentially all responsibility was passed to state and local authorities and the LEPCs. The LEPCs and state and local authorities often do not have the resources or information needed to effectively exercise this responsibility or provide an independent check on industry. Because there has been little activity from U.S. Federal agencies, state and local governments are enacting their own regulations concerning the storage, use, and transportation of hazardous materials. Because the Federal research programs have been terminated in the U.S., much of the information and analysis tools needed for intelligent regulation, either by state and local or Federal authorities, simply doesn't exist. This encourages poor or inadequate regulation and either increases the risk from accidents or makes it unnecessarily difficult for industry to operate. A stronger Federal agency role, both supporting research and gathering and standardizing hazard assessment tools and information, is needed. The Federal agencies could also minimize the chaos being created by proliferating state and local regulations while providing the regulatory oversight needed.

Worldwide

Within the European Community (EC), the member countries have all adopted the 1982 Seveso Directive. This legislation covered both accident prevention and emergency response. It required plant operators to demonstrate to national authorities that they have:

- identified the hazards,
- adopted safety measures,
- provided worker training,
- provided safety equipment, and
- done detailed studies.

The detailed studies are to include studies on:

- plant siting,
- substances and processes at the plant,
- sources of hazard,
- exposed groups,
- preventive measures,

- possible accidents, and
- emergency response plans, and alarms.

In addition, the national authorities must:

- assess the detailed studies,
- supervise implementation of safety measures, and
- organize inspections.

The OECD, which includes the principal chemical-producing and using countries, has the responsibility for strengthening international cooperation for prevention of, and preparedness for, major accidents. It plays a leading role in risk reduction. It has recently endorsed:

- mutual consultation for siting on national borders,
- review of safety of existing installations,
- developing a warning system for accidents, and
- establishing the principle of public right to information.

The EC has recently adopted the OECD decisions.

CHEMICAL ACCIDENTS—CURRENT CAPABILITIES

Industry-based organizations, such as CCPS, GRI, CMA, API, and TFI, and industry-based programs, such as CAER, represent tremendous capabilities to solve problems involving chemical accidents. There is a long history of cooperative work among the various industries making up these organizations. At this time, much of the research being conducted in the area of accidental release of hazardous chemicals is currently being sponsored by these organizations. In addition, there are ad hoc organizations formed to solve particular problems. The Industry Cooperative HF-Mitigation/Assessment Program, involving some 20 companies who are HF users and manufacturers working together to solve problems associated with HF, is an example of such an organization.

The Federal agencies are represented by the National Response Team, the National Response Center, the DOE Spill Test Facility, the EPA Chemical Emergency Preparedness and Prevention (CEPP) Program, the DOT Materials Transportation Bureau and the military services (U.S. Army, Navy, Air Force). They, too, are sponsoring research to develop capabilities to deal with chemical accidents, but this work has been in decline in recent years. For EPA's programs, most responsibility has been passed to state and local authorities. Emergency response teams also exist primarily at the state and local level.

The summary of our technical knowledge and capability lies within computer codes designed to calculate the consequences of an accidental release of hazardous material to the atmosphere. Currently, several 3-D conservation-equation codes exist that are capable of calculating the atmospheric dispersion of dense clouds from large chemical accidents in complex terrain. One of these models includes the effect of aerosols produced by flashing, two-phase releases (1). These models generally require supercomputer capability such as a CRAY. A few more models are capable of 1-D conservation-equation calculations of dispersion of dense clouds in flat terrain with some capability to do aerosol thermodynamics (2). Those models will generally run on small (PC) computers. Both the 3-D and the 1-D conservation-equation models are generally used for planning for accidents. The commercial models are generally not capable of adequately treating

dense gases since most are based on Gaussian dispersion, which was developed to describe neutrally dense tracer releases rather than large-scale, denser-than-air chemical releases.

Atmospheric dispersion models also exist for emergency response purposes. These models are also commonly used for planning and drills, but they are designed to give answers in real-time, during an accident. Because these models are needed in real time, they use input from meteorological instruments as close to the accident site as possible and must be as rugged and simple as possible. The best of these models also account for the effects of terrain on the wind field (3) and for time-varying winds, but none of these models deal adequately with dense-gas releases such as would be characteristic of large-scale chemical accidents.

To validate the models, large-scale, heavily-instrumented field experiments have been conducted over the last ten years (4). These experiments have involved large releases of liquefied natural gas (LNG), liquefied petroleum gas (LPG), ammonia (NH_3), nitrogen tetroxide (N_2O_4), anhydrous hydrofluoric acid (HF), and freon. In each test series, an array of measurement instruments was fielded to collect data to be used to validate models. The FEM3 and SLAB models have been validated over a period of several years using the data from these tests (5,6,7,8,9,10).

There has been tremendous interest in publicly-available models recently because they are open for scrutiny and can be evaluated using dense-gas model evaluation techniques recently developed (11). Except for limited efforts by Havens, there has been no systematic and comprehensive model evaluation effort for dense-gas dispersion models using dense-gas evaluation techniques and the data base of field data. This work is badly needed by both the users and regulators.

Proprietary models are no longer acceptable to many users because there are too many ways of making them give the "right" answer for a particular problem. Models must have an independent and comprehensive review and evaluation by experts using dense-gas model evaluation techniques and a variety of dense-gas data sets

CHEMICAL ACCIDENTS—THE SOLUTION

Chemical accidents will always occur as long as hazardous chemicals continue to play an important role in our culture. The frequency of such events must be kept very low for the public to continue to accept the risks they create. The most important and first line of defense must always be *prevention.* This is the industry position and where industry puts most of its resources. It is also, in my opinion, the proper focus for most of the effort in hazardous chemical safety and must be maintained as a vital ongoing effort. It is, however, mainly up to the various industries to maintain this work.

Since chemical accidents will still occur, in spite of the most rigorous efforts to prevent them, it is also important that regulators, public officials, members of LEPCs, and the industries themselves know what the consequences of such accidents will be. This knowledge will help direct resources and attention at the most significant problems. With industry concentrating on prevention of chemical accidents, it is appropriate that government-sponsored work concentrate on determining the consequences of accidents, if they occur, and on creating fair and sound regulations. Both efforts require knowledge, information (data), and technical expertise, which are developed and maintained through ongoing applied research programs. These programs need to be independent of industry to some degree so that they can remain credible with the public and so that they can deal with any difficult problems that are uncovered. They also need to be closely coordinated with industry so that they are helping to solve real problems, so that they have available

good and accurate information, and so that knowledge and tools developed can be immediately available for industry to use.

Thus, the solution to the problem of chemical accidents is cooperative, multidisciplinary problem solving, involving industry, government, researchers, and the public. If this is done well, it will build confidence in the technology that dominates modern life. This effort must be multinational because the problem is worldwide and because industrialized countries are exporting their technology to the developing world. It must be multiindustry because any particular hazardous chemical is often used in several different industries. It is highly multidisciplinary, involving chemical engineering, atmospheric sciences, mathematics, toxicology, and a number of other disciplines.

Currently, in the U.S., government funding of research into chemical accidents has practically ceased. The needed cooperative efforts will not occur without the government playing its role, both in research and regulation. Some of the current outstanding research needs are listed below:

1. There is an ongoing need for atmospheric-dispersion model development. Currently, no emergency response model can adequately treat denser-than-air chemical releases in variable terrain and with variable wind. Aerosol formation and transport often dominate the dense-gas dispersion process in the early stages. For large releases in stable atmospheric conditions, this can occur for one or more miles downwind. An analysis of aerosol formation and dispersion, for common industrial chemicals and processes, is needed if public officials and LEPCs are to know what the real hazards are for the plants in their areas.
2. Most dispersion-model validation has been very limited and performed by the model developer (Havens, 1987 is an exception) using only selected portions of the data available for validation. A systematic and rigorous approach to model validation has been developed and should be applied to models currently in use by those concerned with chemical accidents.
3. Recently, work has begun on hazard mitigation systems. Extensive studies of the effectiveness of vapor barriers for LNG dispersion and water sprays for HF removal have just been completed. A comprehensive program to develop and evaluate hazard mitigation systems is needed.
4. Vapor cloud combustion and the potential for detonation in a complex industrial environment needs more study.
5. The health effects of many toxic chemicals are not well known.
6. Technology transfer from cooperative or government-sponsored research projects to the commercial sector would provide an immediate public safety benefit. Intense interest has been shown in our atmospheric-dispersion models by both industry and Federal, state and local agencies.

More active Federal government participation, particularly in the research areas mentioned above, is needed in the U.S. This participation would help coordinate, unify, and focus on national problems. The government could also set standards, collect and distribute information, and help out small industries and public entities such as LEPCs by giving them access to expertise, analytical tools (dispersion models), and information that is currently either not available or available to only large industries that can pay to obtain it. It also puts needed information in the hands of organizations that are advocates of public health and safety and that respond to elected public officials.

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OPPORTUNITIES FOR INTERNATIONAL COOPERATION IN NUCLEAR ACCIDENT PREPAREDNESS AND MANAGEMENT: PROCEDURAL AND ORGANIZATIONAL MEASURES

by

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INTRODUCTION

In this paper we address a difficult problem: How can we create and maintain preparedness for nuclear accidents? Our research (1) has shown that this can be broken down into two questions:

- How can we maintain the resources and expertise necessary to manage an accident once it occurs?
- How can we develop plans that will help in actually managing an accident once it occurs?

We will introduce these themes in turn.

As was pointed out in the above reference, it is apparently beyond the means of ordinary human organizations to maintain the capability to respond to a rare event. (We'll define a rare event as something like an accident that only happens once every five years or so, somewhere in the world.) Other more immediate pressures tend to capture the resources that should, in a cost/benefit sense, be devoted to maintaining that capability. We demonstrate in this paper that some of the important factors behind that phenomenon can be mitigated by an international body that promotes and enforces preparedness. Therefore this problem provides a unique opportunity for international cooperation: an international organization promoting and enforcing preparedness could help save us from our own organizational failings.

Developing useful accident management plans can be viewed as a human performance problem. It can be restated: how can we support and off-load the accident managers so that their tasks are more feasible? This question reveals the decision analytic perspective of this paper. That is, we look at the problem of managing a nuclear accident by focusing on the decision makers, the accident managers: how do we create a decision frame for the accident managers to best help them manage? That decision frame is composed of four elements:

- information: the data made available about plant status, action consequences, recommended actions, etc.,
- training: the learned responses developed in past drills, classes,
- authority: who can be commanded to do what, and
- incentives: the rewards and penalties each manager faces.

In the rest of the paper, we will expand on each of the two themes just introduced, referring to examples from American nuclear accidents and other accidents. Then we will take a brief look at parallels with the accident at Chernobyl. Finally, we will assemble the results from the body of the paper into a set of several basic problems with maintaining nuclear accident preparedness, then show how an international, cooperative effort could mitigate those problems.

MAINTAINING PREPAREDNESS FOR A RARE EVENT: AN INSTITUTIONAL CHALLENGE

The difficulties of maintaining preparedness for a rare event are largely institutional. We can sort them into a list of five different but related institutional problems:

1. Budgetary pressures

Day-to-day budgetary pressures of routine expenses are often much stronger than the less concrete pressure to maintain preparedness for a rare event. In a workshop on nuclear safety (1), the head of the Pennsylvania Emergency Management Agency (PEMA) said that he had only three to six months after a major disaster to ask for increased funds for his agency. After that, his state legislature had too many "nonrare" demands on the budget to allocate scarce resources toward preparedness. There is a process of growing complacency in an organization, as the time since the last major mishap grows. This phenomenon was cited in three studies concerning the accident at Three Mile Island (1,2,3), and in a study of the Challenger Space Shuttle accident (4). A vivid example of this phenomenon as it relates to accident prevention can be found in the Exxon Valdez accident.

During the years preceding that accident, Exxon had been systematically reducing the crew sizes on its tankers, including the Valdez (5). In other words, since no accidents were happening, budgetary pressures were pushing Exxon to effectively increase the risk until, naturally, an accident happened. This was not necessarily a deliberate strategy by Exxon, but a natural reaction of a corporation balancing very real operating costs against the less concrete benefits of reducing the risks of a rare event.

2. Difficulties in testing and exercising the system

The three studies of the Three-Mile Island (TMI) accident cited earlier all mention that stress and confusion are key elements in human behavior during such an accident. Yet those are the very elements that are the most difficult to simulate in an exercise. During the 1980 workshop on nuclear accidents mentioned before (1), a West German exercise was described in which phone calls lasted 2 minutes. A participant in the TMI accident pointed out that the phone calls at TMI actually lasted up to 45 minutes, since people asked for more information than planned and it was harder to describe the situation than anticipated.

3. A lack of data and difficulties in learning from that scarce data

Rare events, by definition, do not generate a rapidly growing data base. But more than that, the complacency associated with rare events makes it difficult to implement what lessons there are to be learned.

A key example, again from studies of TMI, is the Davis-Besse incident, a nuclear-reactor incident that occurred a year before TMI and effectively foreshadowed the failure mode of TMI. The learning process was so ineffective, the lessons of Davis-Besse were not used to prevent TMI, or even to understand TMI while it was happening.

Another example is cited in the study of the Challenger accident mentioned earlier: as the shuttle launches continued successfully in spite of problems with the O-rings that were the Challenger failure mode, the agency in charge did not maintain an adequate effort to investigate that failure mode.

4. Difficulties in establishing and maintaining effective plans

In two studies of oil-spill contingency plans, one in response to the Exxon Valdez spill, contingency plans were found to be inadequate (6,7). Typically, the plans failed to specify adequate resources for a spill the size of the Exxon Valdez spill and relied on people and equipment that were not in fact committed to being always available for response (and, in fact, were not available for the Exxon Valdez spill). Even such a simple thing as keeping a 24-hour phone number covered for emergency response has been found to be beyond the abilities of some oil-spill response organizations (8). Apparently, oil spills are too rare to provide adequate motivation to establish and maintain effective contingency plans.

5. Difficulties in maintaining the motivation necessary to implement preparedness measures

In the 1980 workshop on TMI mentioned before, a Nuclear Regulatory Commission official described how, four years after the Brown's Ferry nuclear accident, a local official complained to him of the burden of implementing some local emergency planning measures (1).

> The local official said, in effect, that nuclear accidents aren't going to happen anyway, so why bother. Two weeks later, TMI happened. What this points out is that, although it may be possible to maintain adequate motivation for preparedness among some elite core of dedicated people in a national agency, that is not enough. Preparedness requires the motivated response of people at the local level, too, and that motivation may be lacking. Perhaps the most eloquent and striking statement of this problem, at all levels, can be found in the closing paragraph of the Rogovin Report on TMI (3):

With every passing day, TMI draws less attention. [Current crises] push the nuclear safety question into eclipse. Just as the last major reactor accident, the Browns Ferry fire, slipped beneath the surface of the sea of daily concerns 4 years ago, so can Three Mile Island join it in the coming years. It will take dogged perseverance in the nuclear industry and in the Government to truly learn the lessons of TMI. We are not reassured by what we see so far.

These five problems seem to be ubiquitous, appearing in nuclear-accident preparedness, oil-spill preparedness, and Space Shuttle risk management. In our experience, which includes risk-management studies not mentioned here, these problems are only adequately addressed when there is an effective, external enforcement agency. That is, an agency outside of the one actually managing the risky activity.

USEFUL ACCIDENT MANAGEMENT PLANS: A CHALLENGE AT FOUR LEVELS

The problems of developing useful accident management plans can be viewed as a set of four types of challenges: decision analytic, institutional, political and technical. We shall consider these in turn.

The Decision Analytic Challenge

The accident manager faces a very difficult decision task. He must assess an uncertain plant status, including uncertain releases, then consider uncertain meteorology and demography to calculate a very uncertain population dose, then decide on which countermeasures to execute, if any. Two of the countermeasures, evacuation and potassium iodide, generate their own risks. Any of the countermeasures have political costs. Even releasing information has costs. The Kemeny Commission concluded that the major impact of TMI was not measured in curies or rems, but in the mental stress caused by the various announcements and the evacuation order (2). Finally, the political pressures on the accident managers can be enormous. The head of PEMA, the emergency management agency involved at TMI, indicated that the governor's decision to evacuate was as much a product of the intense pressure to do something as it was a product of careful reasoning (1). Four factors make nuclear accident management especially difficult:

1. Unexpected situations

Unexpected situations lead to unexpected information needs and unexpected alternatives to evaluate. Both TMI and Chernobyl were essentially unexpected situations. No one had foreseen the slowly developing, confusing type of accident that was TMI. None of the plans in place at Chernobyl included provisions for the massive failure of the core structure that occurred there.

2. Uncertainty

The uncertain situation at TMI made it very difficult to assess the severity of the accident, to communicate that severity to other parties, and to decide on actions and countermeasures. Accident management plans should help managers cope with that uncertainty, by being keyed to data actually apt to be available, by providing "smart people" on site at time zero, by specifying a well-defined management structure, and perhaps using such devices as standard paragraphs to communicate the reactor status. Yet the accident management plans reviewed in the 1980 workshop typically don't handle that uncertainty. They would typically assume a well-understood initiating event, then key action guidelines to such things as dose, pressure, or radiation. The problem is that those measures may not exist, or if they do, they may not indicate the danger of higher numbers in the near future. No such index at TMI was an adequate indicator of the reactor status.

3. Split expertise

Accident management involves the interpretation and integration of diverse and sometimes conflicting data to develop a probabilistic assessment of the status of the plant. Yet accident management also involves societal risk tradeoffs (e.g., between the risks of evacuation versus the risks of not evacuating) and the authority to execute countermeasures. This means that somewhere in the management of a nuclear accident a technical person must communicate with a government person.

4. "The human element"

Accident management plans should consider the problem that plant personnel may flee, either out of fear or to help their families deal with an evacuation. In considering these four problems in accident management, combined with the enormous stakes of the decisions involved, we can see that accident management involves an extremely high information-processing burden. Therefore, accident management plans should pre-analyze decisions as much as possible to off-load the real-time task.

The Institutional Challenge

One of the clearest institutional challenges is one of incentives. The NRC requires a reactor operator to notify off-site authorities within 15 minutes of an "event." But will he? Consider his personal cost of placing that call for what turns out to be a false alarm. If there is any ambiguity, he is not apt to call. His threshold

for action is apt to be different than society's optimal threshold. Therefore, stiff penalties are required for nonreporting, to bring those thresholds into agreement. This problem applies also to notifications from one country to another in the case of transboundary risk.

The Political Challenge

The political challenge of nuclear accident management includes two key problems:

- transboundary impacts, for which people bear risk without a role in managing it; and
- political acceptability of the plans and the planning process.

The latter issue includes the problem of the local public's role in approving evacuation plans. Such a role would seem legitimate, but then what if it is used as a means to oppose the siting of the nuclear plant for reasons unrelated to accident management?

The Technical Challenge

The technical challenge in nuclear accident management includes two key elements:

- to collect, process, and display information to support the accident manager's decisions, even when the plant is in an unanticipated status, and
- to maintain reactor control in unanticipated situations.

These will not be discussed further here, since the focus of this paper is on procedural and organizational measures.

A BRIEF COMPARISON WITH CHERNOBYL

Much of the above discussion has been based on the experience and lessons learned from TMI. It would be good to be able to say that the experience at Chernobyl corroborates TMI lessons learned. However, a review of the literature (9) finds that there are not many parallels between Chernobyl and TMI. Compared to the RBMK reactor at Chernobyl, the LWR reactor at TMI, and much of the rest of the world, is much more apt to have a delayed release, for which nuclear accident management plans must address the management of a developing situation. In contrast, the accident at Chernobyl was more of the "classic" nuclear accident, of the type apparently assumed by the typical accident management plans reviewed at the 1980 workshop, in which the focus is on minimizing release from a damaged core and evacuation decisions can be based on reasonable dose projections. Aside from that, the state of emergency preparedness in the Soviet Union at the time of Chernobyl was, frankly, not as developed as that of the United States at the time of TMI.

Nevertheless, there are two features of the Chernobyl accident that do corroborate the TMI experience:

- There was an emergency response plan, but it had so little to do with the actual situation that it was of little or no use, as at TMI. So again, it is difficult to design nuclear accident management plans to deal with actual accidents, which tend to involve unexpected situations.
- The operators under-reported the severity of the accident, as at TMI. Apparently that tendency is not limited to corporate-owned reactors, but applies to state-run reactors as well.

CONCLUSIONS

Several of the problems discussed above can be addressed with a system of international cooperation. In fact, if we outline some aspects of an international agency for accident preparedness, we find that it would be uniquely suited to address several of the problems. Consider first the problem of maintaining preparedness for a rare event. An international agency, by pooling the experience from several nations, can create a situation in which accidents are effectively less rare. The International Atomic Energy Agency (IAEA) has already put this idea into practice with mechanisms for pooling experience from accidents and incidents. What is missing from that mechanism is a means for external enforcement to maintain preparedness. An international agency would be able to provide that enforcement, and so provide leverage for emergency preparedness organizations within each country to argue for adequate funding and priority: "After all, we wouldn't want to be in violation of an international treaty, would we?"

But beyond that, an international agency could pool expertise on accident management plans and provide a critical review of each country's plans. Again here, the effect would be two-fold: pool expertise and provide external enforcement to ensure that adequate plans are in place. To carry the same ideas further, such an agency could observe and even conduct extensive accident management drills, again pooling expertise and providing external enforcement. However, past experience indicates that it is not enough to be able to mount an extensive drill. That is not an effective test of actual, 24-hour readiness. It takes short-notice drills to test that readiness.

While short-notice extensive drills would be prohibitively expensive, the features that need testing with such drills primarily involve phone contacts, administrative structures, and equipment readiness. Those aspects could be tested with phone drills and inspections, which are not expensive. Therefore an international agency could provide an excellent means to maintain and test readiness by initiating short-notice limited drills. There is a parallel here with the short-notice on-site inspections being considered for arms control treaties. Although short-notice drills may seem intrusive in cases for which equipment to be inspected is also part of military readiness, provisions could probably be worked out to cover such cases. The benefits of these drills for maintaining preparedness are so great, it is at least worth investigating the possibility.

Two other accident-preparedness and management issues could be addressed with international cooperation: incentives for rapid notification of accidents and transboundary impacts. The IAEA has already instituted an international agreement concerning rapid notification. However, it should be noted from the incentive discussion above that such an agreement should include significant penalties for failure to notify. Those penalties may only be feasible within the context of a broader agreement setting up an international agency specifically to enforce nuclear accident preparedness and management.

As for transboundary impacts, there already is an agreement involving transboundary liability. What is missing is a mechanism for countries at risk to participate in enforcing preparedness in the countries that hold them at risk. That mechanism could be provided in the form of participation in the measures discussed here: critical reviews of accident management plans, observation of extensive drills, and initiation of limited drills.

To summarize, there are several significant organizational and procedural problems with maintaining preparedness for nuclear accidents. They center on:

- the incentive and data aspects of maintaining preparedness for rare events, including the difficulties of maintaining adequate plans and exercising them;
- developing plans to deal with the several challenging decision-making aspects of managing a nuclear accident;
- early notification of accidents; and
- transboundary impacts.

Those problems can be addressed by an international agency specifically set up to promote accident preparedness. The IAEA has already addressed the problem of limited data on events as rare as nuclear accidents by instituting a mechanism for international pooling of accident and incident experience. The other problems could be addressed very effectively by an agency that:

- provides and requires a critical international review of each participant country's accident management plans, including a pooling of expertise on such plans;
- conducts or at least observes and approves extensive accident drills and requires a certain frequency of those drills;
- initiates, observes and approves limited short-notice accident drills;
- provides sanctions for late notification of accidents; and
- allows nations at risk from another nation to participate in the reviews and drills.

Perhaps the most striking thing about this idea is that such an international agency is not merely one way to address these problems, but it is the best way, since such an agency is in the best position to address the central problems of maintaining preparedness for nuclear accidents: accidents are rare, maintaining preparedness requires external enforcement, and plans can best be developed with pooled experience and expertise.

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CONFIDENCE-BUILDING AND THE THIRD WORLD ENVIRONMENTAL CHALLENGE*

by

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The concept of development at the expense of others is on the way out. In the light of existing realities, no genuine progress is possible at the expense of the rights and freedoms of individuals or nations or the expense of nature. Efforts to solve global problems require a new scope and quality of interaction of states and socio-political currents, regardless of ideological or other differences.

—Mikhail Gorbachev at the UN, 12/7/88—

I am an environmentalist.

—George Bush, 1988 Presidential campaign—

It does not seem overly optimistic to say that the world is leaving behind the Cold War and entering a new phase of superpower relationships. Whether this new detente will turn out to be only a temporary thaw, or really is the first sign of a sea change in US-Soviet relations, remains to be seen. In either case, it is a particularly opportune time to establish confidence-building projects and programs in a number of different areas in cooperation with the Soviet Union. In this paper, I propose that the United States and the Soviet Union give serious consideration to initiating a cooperative program oriented toward addressing existing and future environmental problems and their consequences in those Third World countries that have been the foci of East-West friction and conflict over the past several decades. To the best of my knowledge, no such program exists at the present time.[1]

Third World environmental issues are of concern to the superpowers for two reasons. First, the environmental damage wrought by four decades of proxy wars in the Third World continues to hinder the well-being and economic development of the countries where the fighting took place. Second, the global environmental changes forecast to occur by many scientists—especially global warming—promise to have especially severe impacts in the Third World. To the extent that internal instability in Third World states contributes to or triggers future friction and conflict between the superpowers, anything that can be done now to stabilize societies and economies will contribute to international security in the future.

In this paper, I will address three questions related to this thesis. First, why cooperate on dealing with global environmental problems in the Third World? Second, what are likely to be the most serious ones? And, finally, where should they be addressed?

Why Global Environmental Problems in the Third World?

Global environmental problems[1] do not, by themselves, represent class of issues that are unique in their effect on the United States and the Soviet Union. They do differ from the more "traditional" concerns

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of the superpowers—military and, to a lesser degree, economic ones—in that their causes and consequences are very widely distributed. As a result, managing or eliminating environmental problems often requires a high degree of economic and social intervention into the habits and predilections of individuals and societies (Dorfman 1985). In some instances, the appropriate macro-economic incentives are available to induce individuals to alter their behavior—for example, the rational pricing of inputs into agriculture so as to discourage the cultivation of marginal lands in an effort to control soil erosion. But even this does not address the agricultural practices themselves that may contribute in large part to the problem (see, e.g., Hogg 1987). A similar situation exists with regard to controlling the myriad of sources of greenhouse gases (Lipschutz & Gleick 1989). Thus, it can be said that some of the most socially and politically intractable problems in existence today are environmental in origin or effect.

One unique aspect of global environmental problems is that they are not bilateral or even alliance-based.[3] Whatever their causes, they are not, except in the case of a special set of problems discussed below, the direct consequence of 40 years of Cold War. In many instances, moreover, the United States and the Soviet Union bear a special responsibility for dealing with certain global environmental problems simply because the two countries possess the first and third largest economies in the world and are first and second in terms of consumption of most resources.[4] Finally, while global environmental problems may be politically difficult to resolve, they are not politically sacrosanct in the way that weapons systems and force structures are and hence do not involve the need to protect secrecy, technology, and other such East-West sacred cows.

It might be argued that their very distance from "high politics" makes global environmental problems uninteresting and not very useful as the focus of confidence-building measures.[5] What is so special, some might ask, about East-West cooperation to resolve these problems, especially since all of the other industrialized nations of the world find themselves in the same predicament? It is precisely because of this argument that I suggest Soviet-American cooperation on environmental problems in the *Third World*, where these problems are not so far removed from the realm of high politics that they can be immediately dismissed as unimportant.

Although many global environmental problems affect the superpowers within their own territories, and there are strong incentives to work toward their control, there exists a compelling logic in devising cooperative efforts to address such issues in the Third World. I noted above that global environmental problems are, for the most part, separate from the bilateral and alliance relationships that have evolved during the course of the past four decades.[6] In the Third World, however, these problems do begin to touch on bilateral political relations. In particular, when they begin to undermine the social and economic fabric of societies, they have the potential to threaten political stability in sensitive regions of the world.[7] Among the countries most affected this way are Vietnam, Cambodia, Afghanistan, Ethiopia, the Sudan, Angola, Mozambique, and Nicaragua, all of them coincidently the sites of East-West conflict over the past 30 or more years.

Because of their general location in the tropical latitudes, moreover, these countries could be severely affected by the universal environmental problems described earlier. Generally, one can say that the direct dependence of human society on the renewable resources rooted in the biosphere is even greater in the Third World than in industrial nations, who engage in much more extensive exploitation of *nonrenewable* resources than the former. Since it is mainly renewable resources—and the environmental functions associated with them—that are at risk from the environmental problems we are discussing one must expect the vulnerability of Third World states to be especially great.[8] The nature and magnitude of the universal environmental problems cannot yet be predicted in detail, nor can it be said with any assurance how they will be distributed

among countries and regions (Gleick 1988). What can be said, however, is that the impacts could easily be large enough to entail massive suffering in the countries most severely affected, that the associated stresses could contribute importantly to regional and global tensions, and that the imaginable if unpredictable actions of governments under such circumstances could even lead to a renewal of civil instability and armed conflict (Gurr 1985).

The likely concentration, in the Third World, of the severest impacts of universal and ubiquitous environmental problems—and of the resulting resentments and tensions—will only serve to aggravate an already obvious southward tilt in the potential arenas of future conflict. Nearly all of the major conflicts since World War II have taken place in the Third World,[9] and the reasons are not difficult to find. The major ideological adversaries in the North have acted on the whole with extreme caution along the boundary of the two blocks in Central Europe, where the most importantinterests of the two sides have, until now, been at stake and where the huge concentrations of conventional and nuclear forces underline the potentially catastrophic consequences of a misstep. By contrast, the southern peripheries of superpower spheres of influence—characterized by less stable alignments and less sharply defined interests—have inevitably provided a more tempting arena in which to seek advantage. And the geopolitical proclivities of the two superpowers have emerged in the form of "proxy wars," built upon pre-existing domestic and regional conflicts, to create endemic regions of instability. What the future will bring in the Third World, we cannot say. Although the likelihood of superpower confrontation in the Third World seems to have decreased sharply in this emerging period of detente, we cannot predict with any confidence how the United States and the Soviet Union will behave in the Third World in the future.

What are the Most Serious Problems?

As *universal* environmental problems began to manifest themselves throughout the world, we can expect the effects to be particularly serious in the Third World. But there are also *ubiquitous* environmental problems in many of the states that have experienced proxy superpower wars since the end of World War II, and these countries, too, usually rank high in the geostrategic calculus of the superpowers.[10] The four most prominent universal environmental problems that need to be considered are: 1) climatic change due to emissions of trace greenhouse gases into the atmosphere gases (most importantly carbon dioxide, methane, nitrous oxide, and halogenated hydrocarbons); 2) contamination of the stratosphere with substances that destroy ozone, resulting in increased levels of biologically disruptive ultraviolet radiation at the Earth's surface; 3) acid precipitation caused by emissions to the atmosphere of sulfur and nitrogen oxides, leading to damage to poorly-buffered freshwater ecosystems and impacts on forests and nutrient cycles; and 4) destruction of tropical forests by over-harvesting and land-clearing.

These problems are linked in some obvious ways. For example, net deforestation contributes to carbon dioxide buildup in the atmosphere, and nitrous oxides and chlorofluorocarbons are implicated in both the "greenhouse" problem and ozone depletion. There may also be other linkages that are not yet obvious. Acid precipitation could be affecting certain bacterial processes, thereby increasing net emissions of methane and nitrous oxides to the atmosphere. Significant changes in the timing and frequency of precipitation could affect the availability of fresh water. Alterations in growing seasons might require changes in agricultural practices and lead to reduced crop yields. Changed distributions and intensities of diseases and pests could affect the health and viability of humans, domestic animals, crops, and forests. Additional potential problems include a general rise in sea level, reductions in fish catches, reduced availability of fuel and fiber from forests, and lessened genetic diversity in nature (on which one should wish to draw in seeking to reduce the impacts of some of the other phenomena).

One key element in assessing the magnitude and distribution of effects is that the separation of causes and consequences characteristic of environmental problems of the universal type is likely to be particularly pronounced with respect to the problem of global warming, which was brought to public and political prominence as the result of on-going droughts in the United States and elsewhere.[11] Paradoxically, however, the greater vulnerability to massive societal disruption by universal environmental problems is in the less developed countries, rather than in the industrialized ones. Third World states have much higher fractions of their populations malnourished to start with. They have smaller food reserves and less capacity to buy food from other parts of the world (which would remain a possibility if environmentally-induced crop failures were only regional rather than global). They are less able to alter agricultural practices quickly because of lack of capital and infrastructure. They are more vulnerable to flood and drought because of settlement patterns and lack of reservoir storage. They are subject to greater effects by an altered disease environment.[12]

In terms of ubiquitous environmental problems resulting from war and civil conflict, the list is more varied but almost as extensive in their effects.[13] These problems include: 1) deliberate destruction of vegetation and forests from the use of defoliants (Westing 1984), with resulting widespread erosion as topsoil is washed away (many of these countries are tropical, or in the monsoon belt); 2) high levels of cratering (particularly in Vietnam and Afghanistan) that have rendered large areas of farmland and forest unproductive (Westing 1976; Davis 1988); 3) international destruction of villages and farmlands as a means of terrorizing rural populations and putting pressure on cities (Leroy 1986:174-75); and 4) the creation of a large, disabled and displaced populations that must be housed, clothed, and fed, even though the resources available for rebuilding make it almost impossible to do so. These environmental difficulties are immediate and have many of the same effects as are expected to result from the universal ones described earlier. In both cases, even those resources required for a subsistence economy, much less a market-oriented one, have been so degraded by war or will be so seriously affected by developing global problems, that continued internal instability is almost a foregone conclusion (Novikci 1989).

Where Should We Begin?

There are four problem areas in the Third World that require particular attention and are present in the nine countries listed earlier. They are: agriculture and soil erosion; water availability; forest resources; and energy supply.

Agriculture and soil erosion. Agricultural practices and associated economic factors in many Third World countries have contributed to the unsustainability of food production and high levels of soil erosion (Blaikie 1985). For example, it has been estimated that standard agricultural practices and the cultivation of marginal lands in Ethiopia lead to the loss of somewhere between 500 million and 1.5 billion metric tons of topsoil per year (WRI 1988-89:282). In Vietnam, the effects of years of conflict led to the degradation and destruction of as much as one million hectares of forests and cultivatable land (Westing 1976; Ehrlich, Ehrlich, & Holdren 1977:653-55). Similar impacts have been noted in Afghanistan (Ahmad 1988; Davis 1988) and can be expected to last for many years, if not decades. Population and other pressures have increased the cultivation of such marginal lands, particularly those on slopes, which are much more prone to rapid erosion than level areas (WRI 1986:53). The disastrous Sahel famines of the 1970s and 1980s came about not only as the result of prolonged droughts but also because in many places the pressures of war, population growth, and inefficient economic systems removed the cushions that had often existed in the past (Glantz 1987). In the ongoing conflicts in the Sudan, Ethiopia and Mozambique, drought-related

famine and the destruction of crops and lands has been used as a deliberate tool of war by both sides in an effort to control the movement of populations (see, e.g., Brenner 1987; Clay, et al. 1988)

Although the records of the United States and the Soviet Union in propagating economically efficient agriculture while controlling soil erosion within their own borders are not sterling ones (see, e.g., Batie 1983), there is much that has been learned—particularly in more arid regions—that could usefully be applied throughout the Third World. Furthermore, in a number of the countries listed above, there is a pressing need for restoration of lands damaged as a result of wars and the removal of obstacles to cultivation, such as land mines, unexploded bombs, and craters. Care has to be taken, however, that assistance programs do not have undesirable impacts. They could, for example, have the effect of increasing the costs of food production and thereby undermining the political stability of some countries. The successful diffusion of new food-production and processing technologies depends not only on whether it uses existing resources more efficiently and increases output (the economic argument) but also on the availability of capital to underwrite the costs of the shift and socio-cultural acceptance. The opportunity costs of adapting to new practices may be very high—too high, in fact, for many individuals who operate on the thin edge of economic viability (Blaikie 1985).

Water availability. Adequate long-term supplies of fresh water promise to be a particularly serious problem in a number of the countries listed earlier (Falkenmark 1989). Ethiopia, the Sudan, Afganistan, Vietnam, Cambodia, Angola, and Mozambique all share international river basins with other countries, and potential water supplies in several of these are very constrained (Gleick 1989:Table 4). Few regional agreements on water management exist in these basins and are quite limited in their scope where they have been established. To date, most management programs have focused on the construction of dams and storage reservoirs for power generation and year-round irrigation and less on the way in which available water is being used (see, e.g., Rogers 1986). As a result, water availability is still quite limited in certain sectors.

Distribution infrastructures are also rudimentary in most of the affected countries, and this contributes to serious public health problems (Rogers 1986:41-42; WCED 1987:238-40) that can only be addressed through comprehensive, nationwide efforts. For the most part, however, international financial assistance continues to be available only to develop large-scale water projects that generate capital and exchange that can be used to pay off international loans (IRN 1988). Far fewer resources exist to provide basic public health needs, such as reliable urban water supplies and sanitary facilities.[14] Although it is probably impossible to reconstruct the water distribution infrastructures from scratch, there may be significant potential for water conservation techniques in the United States (see, e.g., Postel 1985; Hudson 1987; James & English 1987), particularly in those regions where agricultural use is high and future supplies may be constrained by urban population growth and long-term climatic affects (Gleick 1988). In irrigation, in particular, widespread deployment of water-saving technologies and techniques such as drip irrigation, lining of canals, abandonment of marginal and salinized lands, and for certain crops such as rice, changes in the frequency of irrigation and the amount of time water is supplied could do much to conserve water resources (Rogers 1986; Nobe & Sampath 1986). There is also a growing awareness of the costs of untrammeled development of water resources in the Soviet Union (see, e.g., Zeigler 1987; Micklin 1988). Soviet and American assistance in designing, financing, and implementing water management programs in countries such as Ethiopia, the Sudan, Angola, and Mozambique could be very helpful in ensuring reliable water supplies for urban and rural use in the future.

Forest Resources. The exploitation of forests is linked to a variety of factors: agricultural demands, international trade, population pressure and "land hunger," and energy needs. Although it is difficult to be

precise about the size of these different demands, it is estimated that in 1982 untouched tropical forests were being logged at a rate of 4.4 million hectares per year with another 7.5 million hectares being cleared for agriculture and other uses (FAO 1982:vii). By some estimates, 20 percent or more of anthropogenic carbon-dioxide production may originate from deforestation (Detwiler & Hall 1988), arising from logging, fuel wood cutting, and "slash-and-burn" techniques, and the resulting destruction of carbon-containing soils. In the countries under consideration, deforestation was considerable, although generally consisting only of a small fraction of the total area of forests in each country (see Table 1).

Population pressure, "land hunger," and demand for fuel wood are significant causes of deforestation in many parts of the world (Gupta 1988:3-16; Spears & Ayensu 1986:299-306). A good deal of forest clearing is followed by conversion to grazing land, to feed beef cattle for urban consumption and export, and much of the logging that goes on provides woods for export (WRI 1987:60). Thus, reducing population growth would have some effect on deforestation but not nearly enough to truly control the latter problem. In many tropical countries, the major population flow is toward the cities and not into unexploited regions (Brown & Jacobson 1987:39-40), although other countries (e.g., Brazil and Indonesia) have made it national policy to encourage migration into the hinterlands. Population control may reduce pressures on forest resources but it will not satisfy a country's desire to lay meaningful claim to all of the territory within its legal jurisdiction. Policies for controlling deforestation include limitations on the conversion of forest lands for agriculture and grazing, moderating demand for lumber and fuel wood, to the extent possible, developing appropriate programs and policies for agroforestry on a broad scale, exploiting remaining forests on a sustainable basis, and if possible, restoring certain tropical and temperate forests (Lugo 1988; WRI 1988:84).

Table 1: Extent of Deforestation in a select Group of Countries

Country	Closed forest, 1980 (thousand ha)	Annual Rate of deforestation 1981-85%	Area deforested per year (thousand ha)
Nicaragua	4 508	2.7	121
Laos	8 520	1.2	100
Vietnam	10 810	0.6	65
Cambodia	7 616	0.3	25
Angola	4 471	1.0	44
Mozambique	1 189	0.8	10
Ethiopia	5 332	0.2	8
The Sudan	2 532	0.2	4

Source: WRI 1986:763

Energy Supplies The provision of adequate supplies of energy for basic needs and economic development is probably one of the most daunting problems facing Third World countries. Basic rates of deforestation are such that fuel-wood deficits exist already in Ethiopia, the Sudan, Afghanistan, Mozambique, and Vietnam and are expected to develop in Angola within the next ten years (WRI 1986:70). The global burning of fuel-wood is thought to contribute on the order of 500 million tonnes of carbon annually to the atmosphere (Rotty 1986:17),[15] and fuel wood deficits are most likely to be met by reliance on expensive fossil-based fuels, such as kerosene. Efforts by industrialized countries to reduce consumption

of fossil fuels—particularly petroleum—as a global-warming control strategy could lead to significant decreases in their costs on world markets. This, in turn, could induce Third World states to further increase their consumption of relatively cheap fossil fuels. This strategy would have the added attraction of shifting energy consumption from potentially "unreliable" renewable sources (as noted earlier) to more dependable nonrenewable ones. Hence, there exist strong incentives for the North to assist the Third World in addressing the fuel-wood crisis and in rationalizing energy policy, as well. Although the nine countries considered here are not unique in terms of their energy problems—and are definitely not major energy consumers on the world scene (even in terms of the Third World)—they are broadly representative of the lower tier of developing countries. Furthermore, they are in need of extensive assistance in rebuilding or developing their energy, industrial, and transportation infrastructures.

CONCLUSIONS

As the largest consumers of raw materials, producers of greenhouse gases, and exploiters of Third World instability, the two superpowers have a major responsibility to address and ameliorate the consequences of their policies there. The economic interests and connections between the industrialized world and the developing South are obvious and likely to grow in importance in the future, even for the Soviet Union. If relations continue to improve, as they have so dramatically over the past year or so, we may be able to say that peripheral conflicts are a thing of the past. To the extent that cooperative efforts now can eliminate potential sources of future conflict and instability and can assist Third World states in their efforts to achieve sustainable development, they are worth initiating. If cooperation can, in addition, take place in formerly contested regions of the world, uncertainty about each other's intentions and motives can be reduced.

A few prescient analysts (Brown 1954; Sakharov 1968) recognized long ago, in some of the chilliest years of the Cold War, that the most intractable threat to peace on the planet would turn out in the long run not to be the ideological confrontation between East and West *per se* but rather the stresses arising from failure to secure the material ingredients of a decent existence for substantial segments of the world's population. If one contemplates the size of the effort likely to be needed to provide a decent chance of avoiding a potential exacerbation of international tensions—both by bringing under control the driving forces behind global environmental degradation and by building up the environmental, technological, and socio-political basis for a sustainable prosperity in North and South alike—it is impressive. The problem requires no less than a major redirection of the scientific, technological, and organizational resources of the planet, in which full East-West cooperation will be essential. In this context, continued bickering about what is left of the US-Soviet ideological dispute is a silly distraction, and the diversion of a trillion dollars per year of the world's economic product into armaments is an intolerable handicap.[16]

FOOTNOTES

1. Although, apparently, the Bush Administration has given some consideration to pursuing this idea in the Horn of Africa. According to a recent article in the *Christian Science Monitor*, a senior Administration official was quoted as saying: "We are all looking at the Horn more in terms of settling its conflicts and meeting human needs than for its strategic importance)" (Wayne 1989). See also *Africa Events* 1989.

2. By "global environmental problems," I mean two types: those that are ubiquitous, in that they occur simultaneously in many different parts of the world (e.g., soil erosion), and those that are universal, in that they have an effect on all parts of the world (e.g., global warming), even though the causes may be ubiquitous. Thanks to John Holdren for developing this distinction.
3. Although, as we shall see, some are not wholly independent of bilateral or alliance-based relations.
4. For example, in 1987 the primary energy consumption of the United States and the Soviet Union were, respectively, 1 849 metric tons of oil equivalent (Mtoe) and 1 444 Mtoe, or 42% of the world total. The next largest consumer was the People's Republic of China, at 700 Mtoe (BP 1988:32).
5. The "uninteresting" quality of resource and environment issues in a bipolar world is addressed by Waltz (1979); see also the literature review on resources and conflict by Lipschutz (1988).
6. For example, in his book *The Struggle for the Third World*, Jerry Hough (1986) makes no mention of resource or environmental issues. See also Lawson's (1988) analysis of Soviet economic aid to Africa.
7. One example of this would be the connections between the droughts in the Sahel during the 1970s and 1980s, the loss of social and political cohesiveness in the countries most seriously affected, and the resulting jockeying by outside powers determined to support their particular group or faction within the affected countries. See, for example, Myers 1986; Clay et al. 1988.
8. There is a certain irony, of course, in the circumstance that the world now seems in greater danger of depleting its "renewable" resources than of depleting its "nonrenewable" ones; but that is what the evidence suggests.
9. Ruth Leger Sivard (1987) lists 119 conflicts involving 1 000 deaths or more between 1946 and 1987, of which all but three took place in the South. This tally includes civil wars and insurrections. The number of wars involving two or more states (including civil wars in which another state intervened) was 60, of which 57 were in the South.
10. I do not mean to suggest that these sensitivities have any objective merit, only that the calculus of geopolitics places particular emphasis on certain countries. See R.D. Lipschutz (1987).
11. More than two-thirds of the greenhouse effect comes from carbon dioxide and chlorofluorocarbons, and more than 75 percent of these gases are generated as the result of activities in the industrialized nations. The responsibility for greenhouse warming in the 1990s is expected to be, approximately, carbon dioxide 55%, methane 20%, chlorofluorocarbons 15%, nitrous oxide 5%, tropospheric ozone and other 5% (World Resources Institute 1988). The geographic pattern of emissions of methane and nitrous oxide cannot yet be specified because the sources of these gases have not been sorted out in detail.
12. It may be argued, on the contrary, that the LDCs will be less affected than the industrialized nations because the greenhouse warming is expected to be greater in the high latitudes, where most of the rich reside, than in the tropics, where most of the poor are found. But this argument is based on a misconception about the main source of damaging impacts: these will come not so much from the average change in surface temperature for a given latitude as from the changes in atmospheric circulation patterns (and, accordingly, patterns of precipitation and of temperature extremes) resulting from the impact of the greenhouse effect on the whole global climate "machine." See, e.g., Liverman 1986, Parry 1986.

13. I exclude from this ubiquitous environmental problems common to many parts of the world that are the result of ordinary human activities, for example, soil erosion, water pollution, population growth, and so on (which are addressed in the following section of this paper). These all need to be addressed, and the assistance of the industrialized countries will be essential to resolving them, but my focus here is on states especially affected by East-West conflict.
14. In 1984, the World Health Organization estimated that some $22 billion per year would be required to provide minimum water and sewage facilities in the Third World, or $10 billion more per year than is now spent on water and wastewater facilities (Rogers 1986:41). Norman Myers (1986:254) cities a UN estimate of $30 billion per year.
15. Estimates of the total annual carbon burden released from the destruction of terrestrial ecosystems ranges from 300 million to 4.7 billion tonnes (Detwiler & Hall 1988:45), of which 420 million to 1.55 billion tonnes are thought to come from the destruction of tropical forests (id.:44).
16. The Worldwatch Institute has estimated that a global program of sustainable development aimed at reducing environmental degradation in the Third World and establishing viable economic conditions there would cost about $140 billion per year for 10 years. If we add in the costs of replacing carbon-based energy sources with other technologies and reducing energy use through greater efficiency (another $100 billion or so), we arrive at a sum of on the order of $250 billion per year. While this might seem like a lot, it is still only a quarter of annual global military spending (Brown 1988:54).

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CHEMICAL ACCIDENT PREPAREDNESS AND PREVENTION: PAST, PRESENT, AND FUTURE PERSPECTIVES

by

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It was over four and one half years ago that methyl isocyanate (MIC) was accidentally released from the Union Carbide facility in Bhopal, India, resulting in a terrible disaster that killed more than 2 000 people and injured thousands of others. The United States and many other countries are still experiencing some of Bhopal's social fallout. This incident has changed the way the United States deals with accidents involving hazardous chemicals. The American public began to ask and continues to ask questions. Could it happen here? What can we do to prevent it? If it does occur, what should we do to protect ourselves?

In response to this concern, the Administrator of the US Environmental Protection Agency immediately developed the Air Toxic Strategy, a broad strategy that addressed both accidental and routine releases of hazardous chemicals. The portion of that program concerning the accidental releases became known as the Chemical Emergency Preparedness and Prevention (CEPP) Program. The CEPP Program recognized that the basic responsibility for understanding risks to localities, for trying to lower those risks, and for responding to an event if it occurs, must take place at the lowest level of government. The program encouraged local response personnel, chemists, scientists, risk evaluators, and physicians to work together both before and after an accident occurs. Analysis of the incident at Bhopal indicates that many lives could have been saved if the public had been prepared for an MIC release. The goal of the CEPP Program has been to highlight the need for preparedness and prevention to protect lives.

Concurrent with the CEPP effort, the Chemical Manufacturers Association (CMA) was designing a program called Community Awareness and Emergency Response (CAER). CMA is a trade association and its program did not have a focused list of chemicals. Instead, CAER provided guidance and advice to industry concerning local community involvement and interaction. The CEPP theme of working together was echoed in the CAER Program. It was agreed that the public is best protected by an integrated program that involves industry working in cooperation with elected officials and emergency managers, governmental authorities, risk assessors, and health officials.

When Congress enacted the Emergency Planning and Community Right-to-Know Act, also known as Title III of the Superfund Amendments and Reauthorization Act of 1986 (SARA), they reaffirmed the basic premise of the work EPA and CMA had begun, added structure and provision of specific information on hazards, and added enforcement authorities in the event industry did not comply with the law. The law placed responsibility for establishing organizations and actually preparing for emergencies at the State and local levels, State Emergency Response Commissions (SERCs) and Local Emergency Planning Committees (LEPCs), respectively. Also, the law required a coordinated effort at the Federal level through the National Response Team (NRT). The NRT consists of 14 Federal agencies, originally brought together to deal with oil spills under the National Contingency Plan (NCP). The NRT responsibilities have been expanded to include chemical accidents, and the law requires the NRT to publish documents providing information for planning.

Title III provides a mechanism for citizen and local government access to information concerning potential chemical hazards present in their communities. This information includes requirements for the

submission of emergency planning information, material-safety data sheets, and emergency and hazardous-chemical inventory forms to State and local governments and for the submission of toxic chemical release inventory forms to EPA. Title III also contains general provisions concerning emergency training, review of emergency systems, trade-secret protection, providing information to the public, enforcement, and citizen suits.

Among the implications of the Title III program are that the primary responsibility to make information available to the public is placed on industry through the reporting requirements. Large companies have complied with Title III for the most part. One of the challenges facing EPA is reaching and educating small businesses about Title III to increase their compliance with the law. Once accomplished, the increased compliance serves to increase public protection.

Participation in the CAER program, provision of logistical support to the LEPCs, providing information to locals in advance of the filing date, and reducing inventories and emissions are additional methods for industry to actively support the intent of the law. Enforcement against facilities that do not comply is a tool to be used by locals and states. This tool can be used effectively to achieve the goal of the law: that of working together with industry to protect the public from major chemical-accident hazards.

Environmental groups have undertaken the responsibility to test provisions of the law, to alert communities to the types of information available, and to keep pressure on the EPA to add chemicals to the lists, if necessary.

Citizens are participating in the process through membership on the local committees; it is estimated that over 50 000 public officials and volunteers serve on the committees across the nation. The system of state and local planning committees was developed to interpret and use the data for preparedness purposes, and fire departments use the data for response purposes. The localities are free to determine for themselves the specifics of how to meet the preparedness requirements and how to follow up with facilities through inspections, code enforcement, reviews, and political pressure. The financial implications of Title III are only now being understood, as the program includes limited federal funding, and the costs for states, localities, and facilities will vary.

The EPA has completed its initial rule-making and economic analysis activity and is now aiding state and local authorities in information management and interpretation through the development of guidance documents. Brochures, technical guidance manuals, and fact sheets have been published and distributed as part of an extensive outreach program.

As another component of Title III, EPA was required to examine chemical accident prevention technologies. Preventing releases of hazardous chemicals to the air, as well as to the water and land, requires a continuous, concerted effort by industry to identify its hazards and provide the technology, training, maintenance, reevaluation, and management vigilance to deal with them safely. It is a continuous process that must take into account the unique hazards of the chemicals and processes, capabilities of personnel, and potential impact on the local community on a site-by-site basis. It must be conducted at every stage in the development and life of a facility, i.e., siting, design, redesign, startup, shutdown, etc. Preventing releases requires commitment at every level in a company, as well as an acute awareness of the needs and shepherding of downstream users. It means a deep need for developing and sharing information on chemical hazards, causes of accidents, and ways to prevent them. Industry has clear responsibility for taking all possible steps to operate safely. Any efforts in this area must focus on making industry meet this obligation and must avoid the establishment of a minimum standard beyond which industry will not feel the necessity to move.

Further, any approach to preventing accidents must involve all key participants, i.e., industry, Federal, State and local government, labor, environmentalists, trade and professional organizations, and academia. It must focus on the development and sharing of information on new technology, improved safety practices, and lessons learned from accidents. Particular emphasis must be placed on reaching the small businesses that handle chemicals. Liability must continue to reside with industry, and ensuring that the necessary information is available will reinforce this.

While Title III has gone far to make information on chemical hazards available, the Agency also has efforts underway to identify causes of significant releases and ways to prevent them and to share that information with industry, the public, and other interested parties. This effort includes the Accidental Release Information Program, which gathers information on causes of significant releases and initiatives taken by industry to prevent reoccurrence, as well as the chemical safety audit program. Recipients of the information include the State Emergency Response Commissions and Local Emergency Planning Committees established under Title III.

Under the Comprehensive Emergency Response, Compensation and Liability Act (CERCLA) and other legislation, the Agency has the authority to investigate releases and has exercised this authority. Recently, the Agency embarked upon an effort to conduct specific chemical safety audits using CERCLA authority. These audits are of facilities that have had a release of a hazardous substance. They address the elements of the facility's program to prevent releases (including the methods used to identify hazards, technologies, and safety practices that exist) to best convey the kind of preventive technology that might be of value in the international area, especially the industrializing nations, while preserving corporate trade secrets and competitive information. The next few years are going to require continuing involvement by the private sector in partnership with government to advance the existing technology.

Finally, the programs initiated under Title III and underway at the international level present great opportunities. They require changed attitudes and the development of new relationships among the various components of the affected population. There must be timely submission and careful and continuous analysis of data. Effective and responsive leadership from industry and government at all levels will be key to program success. Just as important, however, is the active participation of individuals working together toward the common objective of increased public health and safety from the risk of hazardous chemicals.

GLOBAL CHANGE

by

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As a prefatory note, may I express the hope that this session distinguishes itself from the more than 50 meetings that have been held or planned this year on the currently lively topic of Global Change by addressing directly the fundamental driving forces of Global Change, rather than becoming preoccupied with the manifestations of that change, which have already surfaced prominently during this year on the cover of *Time, Newsweek, US World News & Report*, and, yes, *Sports Illustrated.* I suspect that the editors of these worthy publications are too young to be aware of the seminal book, "Our Plundered Planet," authored by Fairfield Osborne more than four decades ago. Incidentally, I commend it to your attention as background reading useful in assessing contemporary interest in global environmental issues.

As a point of departure for the subject I wish to address, I would remind you of a seminal thought contained in the report Global Change: Impacts on Habitability prepared in 1982 on Cape Cod by a small NASA group chaired by Professor Richard Goody of Harvard. They noted that: "The human race lives on a planet characterized by change.... This is a unique time when one species, humanity, has developed his ability to alter its environment on the largest (global) scale and to do so within the lifetime of a single species member."

Within the context of that prescient thought, permit me to outline three theses that seem to me to be relevant in setting a discussion of global change and our common future within the framework of the topic of this conference: technology-based confidence building. They are:

1. We are rapidly approaching the end of the five-century era within which the ebb and flow of military might and economic strength have been the key determinants in the rise and fall of the great powers so vividly and perceptively described by Paul Kennedy in his book by that title. This era was brief, occupying only one percent of the span of years known as the period of modern man and only one-tenth percent of the span of years since homo sapiens emerged.
2. Contrary to the views of that eminent scholar, George Kennan, those astute political leaders Thatcher, Mitterand, and Gorbachev, and the thoughtful participants in the Intergovernmental Panel on Climate Change, it is not the global environmental issues such as greenhouse-gas warming and depletion of stratospheric ozone by CFCs that are becoming the driving forces in international relations. Important as are these issues, they are merely manifestations of the fundamental forces driving global change. These are:
   (a) exponential population growth on a plant approaching full occupancy, and
   (b) exponential growth in the capability to transform natural resources into the goods and services that sustain life and give meaning to sheer existence on a planet where forty percent of the photosynthetic productivity is now used, diverted, or wasted.

   Without denigrating global environmental issues currently in the public mind today, we need to address sooner rather than later, the complex issues of managing global population growth and transforming the industrial/agricultural system that draws on natural resources to meet basic human needs. There is

a regrettable tendency to apply bandaids to the crisis-of-the-year byproducts of exponential population and economic growth. To do so, we must adopt a time perspective that recognizes that just as Planet Earth is no more than halfway through its life expectancy, we should think and act as though homo sapiens is no more than halfway through its life expectancy. This means managing our global affairs in a manner that looks forward to another half a million years of species survival. After all, this would be only a snippet of time compared to the tenure of dinosaurs on Planet Earth!

3. The scientific and technological community has a unique responsibility to identify and illuminate the driving forces of change since:

   (a) Exponential growth in population and potentially exponential growth in the world economy arise directly from scientific and technological advances during the past century or so in the understanding and use of matter, energy, life processes, and information—as well as the interrelationship among these four domains.

   (b) The discussions during the past two days suggest that we have nearly at hand the tools, techniques, infrastructure—and most importantly—the will to make a start. The scientific community stumbled forty years ago, despite Szilard. Let us honor his memory by not stumbling, or fumbling, again. That a great national weapons laboratory convened this conference is a good omen.

It is manifestly clear that science and technology can develop the knowledge base upon which the power of world opinion, operating through governments, can frame public policy that would set a course for the future that has attractive vistas instead of one that places in jeopardy so many of the values that humankind treasures. Is it not equally possible that the coming together of scientists from many disciplines and many nations might offer an example of a mode of thinking that could be adopted by diverse national governments as they address the management of world affairs?

The manifestations of global change are summarized succinctly in Table 1-1, reproduced from *State of the World 1988* prepared by the Worldwatch Institute. Only a few moments of reflection are necessary to be persuaded that these global environmental changes are the direct effects of human activity: more people converting more natural resources into the goods and services that feed, clothe, shelter, educate, and provide gainful employment. The magnitude of the challenge to develop the knowledge base and to make the policy decisions becomes clear in the light of future prospects. It has taken perhaps a half a million years for the world population to reach five billion. There is a high probability that Planet Earth will be asked to accommodate another five billion within the next fifty years. More than ninety percent of that population increment will be found in the developing countries. To meet the basic human needs of many more people and to make up the shortfall in meeting the needs of today's five billion individuals will require a five- to ten-fold increase in the global production of goods and services. It is likely that the "carrying capacity" of Planet Earth will be severely stressed.

Table 1-1. Changes in the Earth's Physical Condition

Indicator	Reading
Forest Cover	Tropical forests shrinking by 11 million hectares per year; 31 million hectares in industrial countries damaged, apparently air pollution or acid rain
Topsoil on Cropland	An estimated 26 billion tons lost annually in excess of new soil formation.
Desert Area	Some 6 million hectares of new desert formed annually by land

	mismanagement.
Lakes	Thousands of lakes in the industrial north now biologically dead; thousands more dying.
Fresh Water	Underground water tables falling in parts of Africa, China, India and North America as demand for water rises above aquifer recharge rates
Species Diversity	Extinctions of plant and animal species together now estimated at several thousand per year; one fifth of all species may disappear over the next 20 years.
Groundwater Quality	Some 50 pesticides contaminate groundwater in 32 American states; some 2 500 US toxic waste sites need cleanup; extent of toxic contamination worldwide unknown.
Climate	Mean temperature projected to rise between 1.5 and 4.5 degrees Celsius between now and 2050.
Sea Level	Projected to rise between 1.4 meters (4.7 feet) and 2.2 meters (7.1 feet) by 2100.
Ozone Layer in Upper Atmosphere	Growing "hole" in the Earth's ozone layer over Antarctica each spring suggests a gradual global depletion could be starting.

SOURCE: Compiled by Worldwatch Institute from various sources.

Stated briefly, the people and the sovereign nations in an increasingly interdependent world are nearing a watershed as we approach the threshold of the Third Millennium. Three options lie before us:

1. to snuff out civilization by releasing the latent power of the world's arsenal of modern weaponry,
2. to strangle civilization by eroding the quality and habitability of the global environment, or
3. to compare a probable future with a possible future and mount the concerted effort to avoid the former and achieve the latter.

Three guiding principles were laid down by the World Commission on Environment and Development chaired by Norway's Prime Minister, Mrs. Gro Brundtland. These are: 1) a more prosperous, more just, and more secure world is obtainable, 2) a policy of sustainable development is the way to achieve this goal—meeting the needs and aspirations of present generations without foreclosing options for future generations, and 3) the quality of the human environment, wise stewardship of natural resources, and socioeconomic development are inextricably interrelated and mutually supportive.

From these considerations, it is possible to state the task and the challenge of global change. It is to describe, to understand, to anticipate, and to manage the dynamic—and often nonlinear—interaction among the great interlocking physical, chemical, biological, and social systems that determine Planet Earth's unique environment for human life that, taken together, govern the rate and direction of global change. The challenge of this task will not be met by business as usual. The holistic nature of the problem requires a holistic approach. A grand convergence among the natural sciences, engineering sciences, and social sciences is required and is already underway. Moreover, it will be necessary to foster worldwide a dynamic and creative interaction among science, technology, and society.

A wise and imaginative balance needs to be achieved—nationally and internationally—between the task of describing, understanding, and anticipating global change and the work of formulating public policy responses. The participation of the social sciences needs strengthening; the role of engineering needs to be made more explicit. The active participation of the private sector is imperative. It is not acceptable to defer action until all scientific issues have been resolved unambiguously. There is a class of salutary actions that can be justified on grounds other than environmental that also address environmental concerns. There is a class of actions that are prudent even in the face of residual uncertainty. There are also, unfortunately, actions that are premature until a better knowledge base is at hand. To discriminate among these options, a new, dynamic, and creative interaction needs to be forged between the scientific and technological community responsible for developing the knowledge base and the decision-making institutions in the public and private sectors that, taken together, determine public policy. This will require institutional renewal, adaptation, and innovation at national and international levels—and in both the knowledge-developing and decision-making domains.

Basic to an appropriate response to the challenge of global change is a fundamental reorientation in our way of thinking—metanoia—among individuals everywhere. Recall the words of Einstein in commenting on the advent of the nuclear age, "Everything in the world has changed except our way of thinking." Ultimately, it is the aggregate effect of individual actions that will maintain Planet Earth's unique environment for life. Individuals shape the collective consciousness; individual consumers make choices that determine industrial policy; individual citizens form the political will to manage change.

Urgency in developing daily initiatives is suggested by the high probability that, in the approximately 4 000 days remaining before the advent of the Third Millennium, the world population will grow by more than one billion individuals—equivalent to the present population of the Soviet Union, Africa, and North America. The task is daunting, but an approach was suggested by Johnny Von Neumann in an article he wrote for *Fortune* more than thirty years ago, "Can civilization survive technology?" After several thousand well-chosen words, he answered his own question: "Yes, probably, provided there is a long series of small but correct decisions."

There is a superb opportunity for the Los Alamos Laboratory, the University of California system, the private sector, and state and federal governments to join forces in a uniquely interdisciplinary approach to build the knowledge base and to propose public policy options for the nation and for the world. My very best wishes to you as you address this challenge.

THE GREENING OF SUPERPOWER RELATIONS: COOPERATIVE VENTURES IN ENVIRONMENTAL PROTECTION AND CONSERVATION OF RESOURCES

by

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INTRODUCTION

We shall not soon forget Ronald Reagan's favorite Russian expression "doveryay, no proveryay" ("trust, but verify"). And as improbably as it all seemed just five years ago, the superpower verification business has been booming. Each day seems to bring with it a new and wondrous event. In June: Chairman of the Joint Chiefs of Staff Admiral Crowe in the cockpit of a BLACKJACK strategic bomber; a team of American scientists measuring the radiation of a cruise-nuclear warhead aboard the *Slava*, one of the Soviet navy's most powerful ships of the line; in 1988 American INF inspectors bringing home shrapnel souvenirs of SS-20 missiles exploded deep in Central Asia; General Akhromeyev on a guided tour of the Pentagon and in a B-1B bomber.

The lesson to be drawn from all this is that no proposal for building confidence is too farfetched. That assumption underlies the content and the thrust of this paper.

PARALLELISM IN SUPERPOWER EXPERIENCES

In energy and the environment, as in many areas, there is a strong element of parallelism in superpower experience.

In March 1979 widespread insecurity over commercial nuclear power erupted suddenly one morning with a partial meltdown at the Three Mile Island plant in Pennsylvania. Seven years later in an equally obscure corner of Soviet Ukraine, this insecurity took on apocalyptic proportions with a reactor explosion at the Chernobyl nuclear power plant. Long accustomed to the anxieties of the nuclear military threat, the superpowers and their neighbors in the global village now were confronted with a new danger—the peaceful atom out of control.

The scorching summer of 1988 drove American and Soviet vacationers to traditional places of recreation: the beaches of the Jersey shore and the Sea of Azov. What they found on the beaches and in the waters—raw sewage and hospital waste—sent many home and enkindled a fire storm of protest and demands to clean up the mess.

When the pristine Alaskan wilderness of Prince William Sound and the lower reaches of the mighty Volga were recently polluted by oil and toxic chemicals, seals and prized salmon and sturgeon were killed by the thousands.

In June 1988 Fyodor Morgun, then chairman of the newly established USSR State Committee for the Protection of Nature, announced at the Party Congress that 102 cities with a population of more than 50

million had degraded air quality ten times in excess of permissible norms. One year later, his counterpart at the Environmental Protection Agency, William Reilly, stated that more than 100 million Americans were subjected to smog-filled urban air well beyond permissible levels.

Since the establishment of diplomatic relations in 1933, never has there been a more propitious time or a greater need for superpower cooperation to preserve the huge portion of the globe with which they are entrusted. As this paper will show, it is time to make US-Soviet relations greener, that is to say more ecologically oriented.[1]

RISING ENVIRONMENTAL CONSCIOUSNESS IN THE US AND USSR

Glasnost (openness) confirmed what most informed specialists have long believed to be true: environmental degradation in the USSR is comparable to and probably far worse than that of the industrial West. By now, in the third decade of our environmental movement, Americans have become accustomed to hearing urgent pleas to "Save the Chesapeake Bay" or "Stop Seabrook Nuclear Power." What is new on the environmental scene in the Soviet Union are similar and equally insistent appeals to "Spasti Aral'skoye More!" (Save the Aral Sea) and "Prekratit' Stroitelstvo Chigirinskoy AES!" (Halt the Construction of the Chigirin Nuclear Power Plant!).

Motivated in part by media exposure and public outcries, the Soviet government has responded with a series of measures aimed at repairing the world's largest and perhaps most distressed industrialized ecosystem within one border. Indeed, ecological consciousness is breaking out in the most improbable of places, in the Soviet military for example.[2] As of January 1988 the Soviet Union has an EPA equivalent in the State Committee to Protect Nature (Goskompriroda) and is formulating an environmental protection plan mapped out to the year 2000.

Thus, at long last, building blocks for productive and sustained bilateral cooperative efforts in environmental protection and conservation of resources appear to be in place. Roughly equivalent national level agencies have been established to monitor the quality of the air and water as well as the handling, storage and disposal of toxic wastes. In contrast to most governmental agencies in the two countries, the mandates, and agendas of EPA and Goskompriroda largely coincide. Citizen-capitalists and citizen-socialists alike prefer clean water and air over polluted water and air; given the choice they would preserve the sable, the sturgeon, the timber wolf, and the bald eagle rather than preside over their extinction.

This heightened consciousness and commitment comes none too soon. After all, in the past ninety years, Mother Earth has been subjected to greater anthropogenic and technogenic changes than in all of prior human existence, and it is beginning to show.

ECOLOGICAL AND GEOGRAPHICAL INCENTIVES FOR COOPERATION

Two countries have been more responsible for these changes than any others. As the first and fourth largest countries in the world, the Soviet Union and the United States are custodians for almost one quarter of this fragile Earth's inhabited area, for the air above it, and for large portions of the seas surrounding it. The two countries together control more than one *billion* hectares of forests. Much of the world's supply of fresh water is found on or below Soviet and American territory. Moreover, although their combined population is only 10% of the world's total, the two countries are in many economic categories the primary producers, consumers, and polluters of the global resource base. For example, in 1985 the superpowers alone accounted for about 40% of all carbon-dioxide emissions—the primary cause of the alarming greenhouse effect.

Thus, the management of just these two environments has a profound impact far beyond the national boundaries of the two countries and affects the quality of the biosphere as a whole. Global environmental benefit derives from prudent and visionary bilateral trusteeship; global environmental degration results from an exploitive and short-sighted approach to this enormous responsibility.

FOCUS ON ARID ECOSYSTEMS

In the interests of enhancing joint trusteeship, this paper advocates focusing on specific pressing cleanup and restoration projects, some of which will positively affect the global commons, that is, the shared resources of the Earth. Some of these endeavors could be administered by jointly staffed environmental protection offices in the capitals of the two countries. Related activities would include taking the ecological "vital signs" of each country at various bases—monitoring, for example, ambient air quality in the ten most polluted urban regions or pooling scientific and technical expertise in attempting to make accurate and timely predictions of earthquakes.

At the forefront of mutual environmental woes are problems associated with water use and abuse, particularly in the arid regions of both countries. These are sufficiently serious, especially in the Soviet case, to merit emergency corrective measures. The fate of one of the world's great inland water resources—the vanishing Aral Sea—might well depend upon it.[3]

The superpowers, it turns out, both have a designation "ecological disaster area." Not long ago, the Aral region was declared such an area (zona ekologicheskogo bedstviya)—with good reason. In the span of just twenty-five years, the Sea was robbed of an amount of water and surface area equal to Lake Erie. The former active seaports of Aral'sk and Muinak are now 30 to 40 miles from the water's edge, and rusting steamships litter the newly formed dunes.

The destruction of the Aral Sea by diversion for irrigation of its primary sources of water, the Amudarya and the Syrdarya, may well rival, in its ecological consequences, the devastating effects of cutting down and burning up the tropical rain forest of Brazil or the aftereffects of the Chernobyl disaster.

Nowhere in the existing cooperative agreements is there provision for reciprocal assistance in coping with the most severe cases of environmental degration—the authentic ecological disasters. However, within the framework of the existing bilateral Project for the Protection of Arid Ecosystems, the United States and the Soviet Union should significantly upgrade joint efforts to resolve the critical problems of water management and consumption they both face.

In the United States the focus would be on the southwest and midwest. It is there that the "mining" of the world's largest underground water source, the Ogallala aquifer, and the almost total withdrawal of once mighty surface resources such as the Colorado River may be the harbingers of potential "wars" over water. In the Soviet Union, the Central Asian water crisis must take priority. After all, the worst case of arid ecosystem degration in the Soviet Union, indeed perhaps in the world, has not recently been studied on-site by American scientists or environmentalists. This may soon change.

On May 30, 1989, a writer from Uzbekistan, T. Kaipbergenov, made an impassioned speech before the Congress of Peoples' Deputies. On behalf of the Aral region, he put out an all-points appeal for emergency assistance. In his concluding remarks he stated:

> Since we are not yet able to rectify the consequences of the ecological catastrophe ourselves, we shouldn't hold the disaster in our bosom. Instead, the world should know everything. We should officially declare the Aral region a zone of ecological disaster and appeal to the world community for help...the shores of the Aral Sea are a forbidden area, top-secret territory

> that reminds one of a reservation: foreign journalists and specialists may not travel there.

The international response to the Chernobyl disaster and to the earthquake in Armenia showed how effective relief measures can be, even when they occur on an ad hoc basis. And recent emergency assistance has not all been one-sided. When specialized vessels were needed to skim oil in Prince William Sound or smash a passage way through the ice to free two trapped whales, Soviet technology came to the rescue.

The Soviet Central Asian water problem—one of enormous consequence and scale—is the result of bad science and technology. About 50 percent of the water in Soviet Central Asian canal and irrigation systems is wasted, poured into the desert, basically. Considerations of conservation have never entered into the crusade for cotton independence via continuous expansion of land under irrigation. In contrast, the United States has designed and constructed some of the world's most efficient canal and irrigation systems. With access, American scientists (hydrologists, engineers, and environmental scientists) might quickly identify methods of conserving the Aral's potential water and at least partially replenishing the sea.

A US-SOVIET INTERNATIONAL PEACE PARK

Prospects for mutually assured protection of wildlife and conservation are bright, as the joint efforts to free the icebound whales off Point Barrow and the oil-spill cleanup in Prince William Sound so poignantly showed. The fifty-six-year-old US-Canadian Waterton Glacier International Peace Park could serve as a model for the US-Soviet nature preserve, a potential UNESCO World Heritage Site spanning the Bering Strait and encompassing parts of Alaska and the Chukchi Penninsula. This project would be an ecological workshop emphasizing wilderness and wildlife preservation.

Bilateral pollution control and wildlife preservation are already under way there. On May 11, in Moscow, Secretary of State Baker and Foreign Minister Shevardnadze signed a US-Soviet agreement to protect the Bering and Chukotskiy Seas from pollution caused by accidents. This small sign of "greening" in superpower relations, though of modest scale, may be viewed as useful spadework for routine and sustained cooperation in the north and projects such as the establishment of a joint preserve. On the Soviet side the agreement is being touted as expanding the scope and horizons of Soviet-American cooperation in environmental protection, while showing that scientific and technical cooperation between the US and USSR is moving beyond the framework of purely bilateral interests, toward the aim of solving global problems as well.

On another imperiled international body of water, the first joint Soviet-American expedition to investigate pollution of the Black Sea just concluded in April.[4]

HIGH-FRONTIER JOINT ENVIRONMENTAL MISSIONS

Additional projects could also be launched to further cooperation and promote confidence building in other spheres. Monitoring airborne pollutants and ozone layer damage involves space research, an area in which both countries excel. A worthwhile start has been made in this direction with the discussions about placing an American monitoring device on a Soviet satellite. But bolder steps should be taken. For example, joint shuttle missions using both countries' orbiters should be dedicated to compiling up-to-date ecological maps of the countries or studying the most critical global environmental problems, including the greenhouse effect, deforestation, and desertification.

Implicit in the ambitious title of Mission to Planet Earth is the acknowledgement that the magnitude of global ecological problems should inevitably redirect exploits in space away from military competition

toward international scientific and technical cooperation. It is now obvious that, among other national factors, a severely abused environment is forcing a radical reconsideration of traditional national-security and defense policies in the Soviet Union.[5]

Space holds great potential for joint ecological ventures. As we have just seen, it offers the best vantage point from which to survey on a grand scale man's inhumanity to nature, especially our handiwork during this century's ninety-year-long gold rush. The shrinkage of the Everglades and the tropical rain forests and the fierce salt-laden dust storms of the dried up Aral Sea bed are best seen from on high. The technology of photographing and mapping the Earth's surface is truly on the cutting edge of science, the military costs of which amount to hundreds of million of dollars and rubles. Daring to declassify some of these operations and images for the purposes of ecological research and analysis would surely build confidence akin to witnessing the destruction of medium-range missiles in Soviet Central Asia or East Texas.

NUCLEAR WASTE PROJECT

Serious and costly problems of the safe storage and disposal of nuclear waste are only now coming to the forefront in the United States, in particular at sites such as the Hanford Production Facility in Washington. Past problems and at least one large-scale nuclear waste explosion in the Urals have recently been admitted by Soviet officials.[6]

The accidents at Three Mile Island and Chernobyl, plus factors such as cost considerations and the threat of earthquakes, have triggered a fundamental reassessment of the nuclear-power programs in both countries.[7] The mishaps were premature by many millions of operational hours, at least according to the projections of designers and engineers.

If there is something positive to be derived from these disasters and from the unremitting depletion of the accessible fossil-fuel base, it may be a new look at alternative sources of energy (wind, solar, geothermal, tidal, and biomass energy). Moving cautiously away from its traditional penchant for monumentalism in energy, the Soviet Union is investigating windmill generated energy. In 1987-1988 the Sate Agricultural Industry of the Kazakh Republic, for example, paid 7.3 million rubles for implementation of a wind-148 were actually delivered. Here, as elsewhere, technical expertise from the United States would speed progress toward "clean" energy.[8]

As things now stand, however, it will be many years before alternative fuels move beyond the pilot project stage and begin to play a key role in shifting energy production and consumption away from overdrafts in the fossil-fuel accounts to energy and environmental security provided by renewable energy resources.

The meantime could be bridged by conservation. Notwithstanding the United States' dubious distinction as the world's most energy-the savings registered by the United States in the wake of the gasoline crisis have been truly impressive. How to almost double a country's GNP on the same amount of energy is a lesson that could profitably be applied in the Soviet Union, among the most energy inefficient of industrialized countries.

THE PRICE OF ECOLOGICAL SECURITY

Though it has not produced a single direct battle, the cold war has been by far the most expensive conflict in history. Financing this war has been responsible in part for plunging one side's economy deeper and deeper in debt and for miring the other side's in an unremitting state of decline, a consignment to perpetual backwardness. In the process a healthy and sustaining environment has been held hostage.

Between 1980 and 1986, US defense expenditures rose from 22.6 cents of every federal dollar spent to 27.1 cents. During the same period, expenditures for natural resources and the environment fell from 2.3 cents of every dollar spent to 1.3 cents. The unprecedented public announcement of more realistic Soviet defense expenditures pegged the defense burden at about 15 kopecks of every ruble spent. According to the latest budget figures, the Soviet government claims to be spending a mere two kopecks on environmental protections.

Given their size and their impact on the global environment, neither country is now doing enough to enhance national and international "ecological security." Yet, if superpower relations continue to improve, if they can become "greener," there will be excellent opportunities to harness an inherent spirit of adventure in the countries to the resources and technology for solving together some of the critical environmental problems threatening the life-sustaining biosphere of the Earth.

Finally, the soviet Union and the United States must move beyond bilateral relations, as the global ecological crisis fully warrants, and exercise, as never before, their powerful leadership roles among their allies and in the United Nations to ensure that the ecological record of the next century will be a vast improvement over that of this century.

REFERENCES

1 The term "to green" (pozelenet') has become popular in Gorbachev's Soviet Union. In his concluding remarks to the Congress of Peoples' Deputies on June 7, Chairman of the Council of Ministers Ryzhkov was applauded when he agreed with prominent biologist and environmentalist Yablokov's call for the Party to become green (pozelenet') quickly and decisively. *Pravda*, 10 June 1989, pps. 3-4.

2 Two examples of evidence of the Soviet military's "greening": "Armiya i ekologiya," (The Army and Ecology), *Krasnaya zvezda*, 8 January 89, 4, and "Ekologiya garnizona" (Ecology of the Garrison), *Vestnik protivovozdushnoy oborony*, No. 3, 1989, pps. 76-79.

3 Although still largely unpublicized in the West, the Aral Sea disaster will surely rank among the greatest ecological catastrophes of the twentieth century. A Central Asian emigre writer recently asserted that more than a thousand articles on the Aral Sea disaster have appeared in the local press of Central Asia and Kazakhstan in the past three years. R. Nazar, *Central Asian Survey* 1 (1989), pps. 49-68.

4 TASS, *Pravda*, 12 May 1989, pp. 5, and Spiridonov, *Literaturnaya gazeta*, 14 June 1989, pp. 8

5 Now one can only guess how much of the cutbacks in Soviet defense spending will be redirected to environmental protection. Ryzhkov stated in his report to the Congress that funds "to cure the existing unfavorable ecological situation" will be tripled (from 15 billion rubles to 45 billion) in the coming five-year plans. *Pravda Ukrainy*, 9 June 1989, pp. 3.

6 Yevgeniy P. Velikhov, Vice President of the Soviet Academy of Sciences, in talks with reporters in Japan, confirmed the reports of a serious nuclear accident in 1957 at a military installation near Sverdlovsk. KYODO in English, FBIS-SOV-88-235, 7 December 1988, pp. 97. Z. Medvedev and A. Roberts, *Hazards of Nuclear Power*, Nottingham: Spokesman, 1977.

7 Just last month Californians voted to close the Rancho Seco nuclear power plant for reasons of cost. The Shoreham Plant on Long Island has been put on hold and may never generate electricity for failure to ensure adequate evacuation in case of an accident. In the Soviet Union, construction at the Chigirin (Ukraine) nuclear power plant and operations at the Yerevan (Armenia) plant have been halted.

8 *Sovetskaya Rossiya*, 28 May 1989, pp. 3. The author asserts that wind-energy power potential is greater than the energy potential of all the Soviet rivers.

MISSION TO PLANET EARTH

by

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I am happy to address this conference on confidence-building measures about the subject of Mission to Planet Earth, a topic that is receiving increased attention recently. I believe that my topic is very timely because many of us in many nations now know that we must begin dealing seriously with environmental issues on a global scale. Is not our common concern about environmental matters a valid basis for tackling these problems together—and building confidence as we join in the process? Even our national leaders are taking notice of the importance of the topic, and it is the subject of discussion at meetings of heads of state.

Whereas only a few years ago, most people were not concerned about the environment, recent public opinion polls show that 3/4 of the people in the US regard it as a primary concern that demands more attention than it is getting. Many have gone even farther in their thinking, to the point that they think we are in a serious environmental crisis. Although I believe that we should face our problems rationally, it is possible that the air of crisis is doing us a favor. It presents the people of all the Earth with the threat of a common danger. It is usually easier to elicit people's cooperation in facing a common danger than it is to get them to cooperate on some worthy but altruistic purpose.

Because of the threat, there is a surprising degree of consensus that the problem is real, that we must change not only our ways of behaving but our ways of thinking about our world. There is also a feeling that we need both new policies and new leadership from the top to deal adequately with what faces us.

All of this leads me to consider how we can use our space assets to improve our knowledge and equip us to deal with the environmental challenge. The title Mission to Planet Earth refers to a continuing study of the Earth from space. One of the principal points of this paper is that space is the place to gather most of the data we need to understand the Earth for the first time in all its beauty, glory, and increasingly recognized vulnerability. Mission to Planet Earth is a research program aimed at coming to know in detail our Earth and the changes that are taking place in the environment in which we live. It includes studying "natural" changes that seem to be due to internal processes in the Earth as well as the effects of energy and particles arriving from outer space. It includes the effects of living organisms, including people, on the Earth.

Last year, the Space Science Board at the National Academy of Sciences carried out a series of studies under NASA sponsorship with the general title Space Science in the Twenty-First Century. A subgroup, the Task Group on Earth Sciences, wrote a report that was called Mission to Planet Earth. Their choice of title seems very appropriate and explains my use of the term.

Many people are becoming concerned about man's threat to his environment. More and more of us are beginning to recognize the need to become conservationists in respect to Planet Earth and its resources, which we now know are not unlimited.

There is growing evidence of serious damage to what might be called the fragile parts of our environment. Witness the erosion of topsoil in once productive areas, growth of deserts, pollution of lakes and ocean shorelines, deforestation in the Amazon Basin, and the loss of many species of plants and animals. Many of the worst problems are in countries least able to deal with them. Overintensive farming, grazing, and rapid population growth are damaging vast areas in many Third World countries.

Increasing numbers of scientists and others are speaking out, describing with varying degrees of certainty why the Earth is changing and what humankind may be doing to accelerate that change. Many of the changes are visible to anyone who will take the trouble to notice; others demand a level of understanding that may require a lifetime of effort. Although we can see the growth of deserts, we do not know all the causes, nor do we know how much of it is man's doing. Although we have measurements showing the increasing amounts of carbon dioxide in the atmosphere for two hundred years, we are not sure how rapidly the increase will raise the temperature of the Earth or affect life as we know it.

Many environmental groups have taken on the task of warning us of the need for protection and conservation; many have enviable records of raising the public consciousness about possible negative consequences of our actions. New groups spring up each year as environmental issues appear more frequently on the front pages of our newspapers. The beleaguered Earth was named Planet of the Year by Time Magazine in its first issue of 1989.

How can we sort out the environmental damage for which we human beings are responsible when these changes are superimposed on the truly awesome effects of tornadoes, hurricanes, earthquakes, tidal waves, volcanic eruptions, and plagues of locusts—all of which occur without our intervention?

As difficult as it may be, we must learn to assess our environmental impact against the backdrop of both our historical knowledge and those fossil records such as tree rings, ice cores, and lake bed sediments, that show that the Earth has been cycling through a wide range of climates and other upheavals over the eons of the past—long before humans had any effect on the environment and long before anyone even considered whether we could become a dominant force in nature.

We cannot hope to deal with the issue of human effects on the environment without having a much greater knowledge of the many interactions that take place between living things on Earth and all the natural phenomena that proceed on their own. For millions of years, humans were not very important environmentally, having some but not very much effect on the world.

When we began to domesticate animals and plant crops, we introduced new stresses on the natural arrangement of things. Grazing domestic animals and cultivated crops caused erosion beyond what had been happening naturally. So within the last five to ten thousand years, we have begun to have some effects on the state of health of the Earth.

Just 200 years or so ago, the Industrial Revolution began to have important consequences. We began burning fossil fuels, usually very inefficiently. For a time, these effects were quite small because of the relatively small numbers of people and machines involved. Starting in this century, and to a much greater degree in the latter half of this century, the effects began to accelerate.

Miracle drugs wiped out many diseases, accelerating an already exponential global population growth. Citizens of many countries became affluent, raising their use of energy by a factor of ten or so.

Before we are ready to do anything other than being generally careful about energy conservation, reducing birth rates, stopping topsoil erosion, and a few other things, we have to reach a new higher level of understanding about just what is going on in the environment.

We need to understand a lot more about the natural rhythm of things. What is the natural evolution of the Earth in the absence of mankind? We must first understand the Earth as an "inanimate" object, then learn about the effects of living things on it, and finally, what our own actions may be doing.

Major efforts are necessary to investigate plate tectonics and movements of the Earth's crust, interactions of such movements with volcanoes, ocean waters and minerals, and much more. The historical and present roles of plants and animals in bringing about major changes on the Earth must also be looked at in depth.

Changes in the Earth's magnetic field and its interactions with the solar wind, natural variations in trace gases in the atmosphere, variations in the Earth's orbit, its tilt and eccentricity, and changes in the solar constant—all these are partly responsible for the fact that we have had major changes in climate in the past, including the recurring ice ages. There are undoubtedly other factors at work affecting climate besides the ones we think we know about.

To explore these matters adequately, we need a true sequel to the IGY, the International Geophysical Year, which took place just as the Space Age was beginning in 1957-58. Some 30 000 scientists in many countries conducted extensive studies of the Earth during an 18-month period at that time. The IGBP, the International Geosphere Biosphere Program, is one of the sequels to the IGY in which our National Academy of Sciences and other similar organizations worldwide are becoming very active. Another name connected with the IGBP is Global Change. The National Academy's contribution to IGBP includes the work of its Committee on Global Change.

Although IGY dealt with the physics of the Earth, IGBP is not just another physical look at Earth phenomena, but also involves studying the biota of the world and the correlation of the presence of life to other observed effects. Living organisms affect the environment so markedly that there is no way to understand global change without taking their existence into account. This would be true even if we could set aside human effects (which we can't).

Mission to Planet Earth, the space-based efforts to collect appropriate data, cannot teach us everything we need to know about the Earth. Such work must be supplemented by measurements made on land and in airplanes, sounding rockets, balloons, shore stations, ships and buoys to yield a complete picture.

All this must be accompanied by development of more realistic mathematical computer models and extensive interdisciplinary analysis, with results compiled in various ways to provide increased understanding of hundreds of essential parameters about the environment as seen from a worldwide perspective.

Mission to Planet Earth is the space-intensive look at Earth-related phenomena concerning globalrival in interest and commitment our exploratory missions to the other planets of our solar system and makes a claim for our support in exploring the most important planet of all.

Because rain, droughts, wind, and ocean currents recognize no national boundaries, multinational efforts are essential if we are to gather the necessary data on a truly global basis. All countries must be involved in the data collection effort, and each nation must do its part. Because spacecraft can collect global data more quickly than any other means, spacecraft must play a key role in our program.

Such work could well be one of the 3 or 4 principal foci of NASA's activities for the 1990s. Carrying out Mission to Planet Earth is a way for NASA not only to do necessary work that no other US agency can do, but also to confirm that NASA is interested in what might be called real world problems. Focusing on Mission to Planet Earth would strengthen considerably the support of NASA by those who now applaud the agency's role in increasing our understanding of the universe but do not see NASA doing much to improve our everyday lives.

NASA is of course not the only US agency with an interest in the changes in our environment, nor the only civil agency with a mission in space. NOAA, the National Oceanic and Atmospheric Administration, has an extremely important role in environmental monitoring and Earth sensing. Even so, NASA is the

major agency with the charter to do research from space about the Earth and near-Earth space, and I believe NASA should take the lead in this activity.

Laying out an adequate program to study global change and enlisting the cooperation of all appropriate US groups is a major task in itself. The number of separate agencies involved makes it necessary that the Office of the President be active in assigning tasks to assure a cooperative attack on the problems. In addition to the policy role of the newly reactivated National Space Council (which is chaired by the Vice President), other agencies with major responsibilities include the National Science Foundation, the Environmental Protection Agency, the United States Geological Survey, and the Department of Energy. Other interested Departments include Defense and Agriculture. Air Force weather satellites are important assets, and their GPS (NAVSTAR) satellites will enable scientists to locate many measuring instruments in space and elsewhere with extreme precision. The Navy has a key role in understanding and predicting ocean behavior, without which we cannot hope to understand climate. The private sector must also contribute to the process. Organizations like NCAR—National Center for Atmospheric Research—also have extremely important roles.

In 1985, Senator Spark Matsunaga proposed that the year 1992, the 500th anniversary of Columbus' voyage to America, be designated the International Space Year. His vision was that the ISY would be a time of enhanced use of space to achieve a better understanding of our world and our universe. His resolution was endorsed by both houses of Congress and signed by the President. I became chairman of the US Association for the International Space Year, and the senator's former assistant, Harvey Meyerson, became the president.

US-ISY has planned scientific conferences to promote ISY. For example, we worked with NASA to hold the conference at the University of New Hampshire called the ISY Mission to Planet Earth Conference in April, 1988. At that meeting, SAFISY, the Space Agency Forum for the International Space Year, was formed, with 17 nation's space agencies participating. The group had grown to 24 nations at its most recent meeting in Rome in May of this year. Dr. Hubert Curien, now Minister for Research and Technology in France, was chairman of the conference and has continued to chair meetings of SAFISY.

SAFISY is a mechanism for convening the heads of space agencies and their scientific and technical representatives to coordinate their activities on Mission to Planet Earth. At the conference in April of last year, all countries with important roles in Earth sensing were in attendance. After hearing what work was underway in various nations, they quickly agreed that their programs of Earth sensing should be much more closely coordinated.

Impressed by the immensity of the task of environmental data collection, the conference proposed setting up pilot projects in a few selected fields. This would enable cooperating countries to work out detailed mechanisms to achieve successful end results before tackling the full range of environmental issues. As an example, they discussed the Greenhouse Effect Detection Project. The project would collect detailed data on local and regional temperature averages and extremes, making comparisons of what is observed with what the best models predict.

Many measures of global change must be collected, such as levels of ozone and other trace gases, temperatures, pressures and humidity of the atmosphere, rainfall, soil moisture, and winds in as many locations as possible. Changes in rainfall patterns and the effect on plants and animals, the extent of cloud cover and its correlation with sea surface temperature, the melting, if any, of ice in Antarctica and Greenland—all these must be measured.

A seemingly obvious but valuable conclusion reached at the conference was that data collection is not an end in itself; rather, the objective is to derive information about our planet to enable us to make decisions. So our group stressed the need for "end-to-end" management of the data handling process. We must combine data from many sources and do it properly to reveal useful information. Rather than starting out focussing on the data, we should describe the desired goals of the exercise and then develop a plan for reaching those goals. End objectives determine our information needs, and these needs should determine data collection methods. Data requirements should drive the design of satellites and other platforms; data processing systems capable of coping with the huge volumes of collected data will be necessary.

SAFISY agreed to set up panels to advise it on science and technology and on education and training. It agreed that we should plan for a 15-year program of Earth observation so as to learn enough to enable us to act properly in dealing with the ecology of Earth as a complete system.

The conference established several working groups. One of the working groups compiled a list of all the spacecraft that the various countries were planning to launch over the next decade to study the Earth—land, water, and atmosphere. Most of us were surprised to see 48 satellites on the list. Equally surprising to me was that this was the first time the participants had ever seen the total list put together.

About half the satellites on the list were designed to create images of the Earth—that is, to make what look like pictures even though they may not be made with visible light. Most of us have seen these images in which infrared emissions or reflections are rendered visible to create special effects. Such satellite sensors are good for studying and predicting weather and for looking for currents and life forms in the ocean, pollution in streams and lakes, blight in crops and forests, snow buildup in mountains, the aurora over the Poles, and many other interesting and important phenomena.

The other half were of various types designed to measure radiation in such a way as to determine the amount of water vapor and various other gases in the atmosphere and the temperature of these gases at different altitudes. With combinations of sensors working together, we can do surprisingly well in determining the physical characteristics of the atmosphere by making measurements from space. Space data must be calibrated by making direct in situ measurements within the atmosphere, on the ground, and in the oceans. Some important parameters are not easily measured from space, including precipitation, ice thickness, heat fluxes over land and sea, and cloud radiation. These must be dealt with by other means—that is, by measurements made at the specific locations of interest by instruments that have been accurately calibrated and installed by people on the site.

Such measurements are essential if we are to determine accurately what is called "ground truth," i.e., what the true conditions are that prevail on the surface and in the air and oceans. Satellites are marvelous instruments for collecting data globally, but are somewhat crude in measuring vertical profiles of various gases and other phenomena because they are several hundred miles above the regions they scan.

If we are to get the complete picture necessary to an understanding of the Earth, it is obvious that each country must be involved. Although only a small percentage of the countries can put up satellites, every country can afford to collect ground truth. To reduce the cost of collection of the data, and to feed back to all countries the bigger picture that will help them understand climate and other effects, what we need is a partnership among those few countries operating in space and those many that will not go into space but which must be a part of the worldwide data collection effort.

Satellites have an important role in maximizing global data collection while minimizing cost. For a number of years, we have operated a system in which ground data-collection platforms transmit the data they collect to stationary satellites, which in turn relay the data to a central collection point. Satellites that

perform this relay function are the same weather satellites (called GOES) that collect the information that we see on the nightly news. A partnership can be developed by those countries operating such satellites and all other countries; we can do on a grand scale what we have successfully demonstrated in a small way for our own needs. Satellites capable of operating in this mode are now in position all around the world. They can collect the data from ground instruments in essentially all countries. In the appendix, I will elaborate on specific features of this method of data collection.

The agreements reached in New Hampshire confirm the worldwide recognition of the need to study global change and the desirability of avoiding unnecessary duplication and insuring inter-changeability of data through common calibration standards. At the SAFISY meeting this year in Rome, the findings of the working groups established last year were reported and in turn were endorsed by SAFISY.

Now that we have achieved our first objective of getting our fellow voyagers on Earth to meet and consider our situation, what should be the US role? The Space Act of 1958 calls for the US to exercise leadership in space. What better task can the United States take on to show such leadership than one that may be the key to enabling the job of global resource management? Because a major fraction of the collection effort can and must be done from space, NASA must be a key player in coordinating this multinational effort. Although working in space will not solve all our problems, it is a necessary component of what must be done.

During the IGY, we found many scientists in Third World countries were eager to participate even when the instruments available to them were not the best. Not only did they collect much valuable information, but they were the local representatives of the scientific community and, as such, were an essential link between their local governments and the worldwide IGY exercise. Similarly, we must make sure they are involved in Mission to Planet Earth because, once more, they will have a key role in insuring that their governments take our mutual problems seriously.

Those of us in space activities must count on our social scientists, health professionals, industrial and political leaders to find ways to curb the global population explosion, including the growth in countries for which the per-capita energy consumption is highest. A necessary step is dealing with infant mortality andlow status of women in many countries. Such efforts are probably even more important than what we plan to do in space. The United States can play a leadership role on many of these social issues by convening multinational working groups of professionally qualified people.

We now know that a broad interdisciplinary effort is our only hope for dealing with our environmental problems on the scale that is required to achieve success. Only by laying out a clear plan for action, using the talents of all parties, and showing how all will benefit can we enlist the necessary international cooperation. Only with such cooperation can we build the consensus and accumulate the data necessary to a global understanding of the environment and the consequences of unbridled use of resources. Only by having the complete picture can we explain to political leaders around the world what is happening, what must be done to curb harmful actions, and how to balance our use of Earth's resources with the ability of nature to sustain them. Only through the cooperation of all can we succeed in rolling back man's worst deeds in environmental damage and begin to restore the natural beauty and viability of our world.

The consequences of not doing what we know we must do are too devastating to contemplate. Now that we are beginning to appreciate those consequences, I believe it is obvious what course we should take.

Most of the other things we may do in space will be for naught if we do not begin doing a better job of using Earth's resources in a responsible manner. Mission to Planet Earth can help us learn to do just that; it is, in my view, the most important thing we can do in space.

APPENDIX

Examples of International Cooperation In Collection of Meteorological Data.

Addendum to paper on MISSION TO PLANET EARTH.

This addition elaborates on a point made in the basic paper about opportunities available for increasing international cooperation among the nations on collecting data for Mission to Planet Earth. Almost all nations now know of the critical need to do something specific and constructive about MTPE, because they have come to appreciate the importance of what is called Global Change and the role of humankind in bringing it about. This addition covers specific collection efforts that lend themselves to a cooperative approach.

Several kinds of joint initiatives are attractive:

a) cooperation among partners having rough equality in ability to operate in space with assets they each have developed in their own country. Such countries are the US, the USSR, Japan, and the ESA countries (to include Canada).

b) cooperation among the countries that are totally space capable (those listed above) and those who are in the process of upgrading themselves to a high state of space capability. Such countries are Brazil, China, India, Israel, Korea, Mexico, and perhaps Pakistan and Argentina.

c) cooperation among the first two categories and the great bulk of countries (more than one hundred of them) that would like to operate in space in some way but do not have the infrastructure (including manpower) to permit them to be effective in this way.

I believe that the greatest need among the first rank countries (type a) is to learn to work together more effectively, based on recognition of mutual objectives, and the need to conserve resources by avoiding duplication (except in those cases where duplication is justified). At one end of the spectrum, we find countries doing what we saw in New Hampshire and Rome—that is, the heads of space agencies (SAFISY) met and agreed to exchange information about planned space activities in each country. This is another way of saying that SAFISY has not yet taken radical steps to cooperate but has made good progress on confidence building among the representatives and is moving toward rather complete data exchange on projects that are already underway.

At the other end of the spectrum, the space-faring countries might agree to form an INTELSAT kind of consortium to collect data with a fleet of satellites that they have jointly funded. In the ultimate case, we might find that the satellites have been constructed according to a formula that allocated work among them in proportion to their expected use of the resulting data.

An intermediate case is provided by ESA, a group of like minded countries that have cooperated to build space systems that accomplish mutually agreed objectives. Some of their projects illustrate the versatility of their arrangements for cooperation, in that not all countries have to support all projects.

The second (type b) cooperation involves countries that are the leaders in space activity and the next tier, which are in the act of becoming space capable. It includes an extension of what is already going on. For example, about 15 or 20 countries have installed Landsat receiving stations. This permits them to join the club, so to speak, reading out data from space even though they have no satellites. The ground stations necessary for this approach may be built in the country or may be bought from commercial sources outside. This kind of thing can be expanded indefinitely. For example, several countries that began by receiving Landsat data are now receiving SPOT data as well. It is a logical step for those same countries to

generalize their data collection efforts and to modify their equipment to receive data from many satellites that are expected to operate in the future. If China puts a satellite in orbit, why should not those 20 ground stations already installed in various countries be modified to permit them to receive data from the Chinese satellite? Certainly, it becomes easier to receive a third data set after one has already mastered the art of building a ground station that receives data from more than one source.

Other cooperative use of satellites involves countries reading out data from weather satellites operated by the space-faring nations.

The third type (type c) cooperation is illustrated by a Third World country installing a data terminal in a major river. The data terminal senses and records several interesting parameters like water depth above mean level, salinity, acidity, bacteria count, temperature, flow rate, and water quality (they might want to measure turbidity, for example). The data terminal incorporates a receiver-transmitter, sometimes called a transponder. When a suitable satellite sends a query to the ground station (data terminal), the ground station transmits the data stored in its memory over the last few minutes or hours to the satellite. The satellite in turn relays the data to a central data-analysis station in the same country, if it exists, or to a mutually agreed upon data-analysis center in another country. The data may enter the public domain and thus be available for all people who want to follow weather patterns on a worldwide basis.

Another powerful illustration involves weather balloons, which was practiced on a limited basis during GARP. A transportable box is prepared in a space-capable country and then shipped to a country that agrees to cooperate in collecting meteorological data of mutual interest. The box includes an array of atmospheric sensors, a transmitter, a balloon, and a bottle of helium. At the appropriate time, someone (not necessarily trained in meteorology) opens the box, causing the balloon to inflate and ascend into the atmosphere. The sensor package measures the desired parameters and information about the atmosphere as the balloon flies to higher and higher altitudes. This is an excellent example of how countries of vastly different capabilities can join in an activity that gives to each something very important; the country that uses the balloons gets the information it needs about the local situation; the world meteorological community gets the data to round out its picture of worldwide weather phenomena.

A refinement of this, which I heard about on a recent visit to NCAR involves using a balloon that, in addition to the weather sensors, includes a GPS (Global Positioning System) receiver. The transmitter that broadcasts the signals from the weather sensors also broadcasts the GPS signals received on the balloon. This allows the central data-collection point to track the balloon's position and velocity, giving an accurate measurement of winds aloft as the balloon ascends.

Another example involves the use of UHF Doppler wind profilers. These relatively simple low-powered short-range radars pick up back-scattered signals from small particles blowing in the wind. A simple processor reads out wind velocity as a function of altitude. The results are picked up by a GOES or a similar satellite for relay to a central analysis point.

Measurements by instruments detecting trace constituents in the atmosphere can be operated in similar fashion. The problem is to make the instruments reliable enough that they can be operated in routine fashion by relatively untrained people.

Another instrument that could be installed inexpensively in many countries is an automatic rain gauge. This is an optical device that measures attenuation caused by rain. This signal can be sent to the satellite from thousands of installed rain gauges, yielding much valuable data not now received about rainfall and not readily measured by satellite. Technicians in the host country should be able to maintain the simple

instruments contained in such devices. Soil moisture can be measured by various instruments including temperature-measuring devices, the results of which can be relayed to the GOES weather satellites.

Some Third World countries can read out data from weather satellites, a capability referred to above, and a few can read out Landsat and SPOT data also. These readout techniques allow the poorer nations to get data quite inexpensively; data that cost a fortune to collect is thus made available at bargain rates.

I believe that my list shows that there are many examples of how relatively poor countries can play an extremely important part in data-collection efforts. Space assets working with these sources of data can give us the worldwide picture we need. In some cases, the equipment to collect the data may be supplied at no cost to the host countries.

Let us hope that over time, all countries will recognize the need to collect data everywhere and will see the benefits accruing to them by participation in such activities.

INHERENT SAFETY IN NON-NUCLEAR APPLICATIONS

by

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SUMMARY

The concept of inherent or passive safety is receiving considerable attention as the basis for the design of the next generation of nuclear power reactors. There is a tendency to speak of the concept as representing advanced technology. The purpose of this paper is to caution against such an association. The paper examines examples of the application of the concept, some of very long standing, outside the nuclear arena and reviews the impetus given to its development in the chemical industry as a result of the major explosion at Flixborough, UK, in 1974.

INTRODUCTION

Inherent or passive safety can be defined as seeking to ensure safe performance by the avoidance of design features whose failure can precipitate an accident or of operating conditions whose presence can exacerbate the consequences of an accident. T. A. Kletz (1), a principal proponent of the concept in the chemical industry, has summed it up by quoting Henry Ford: "What you don't fit costs nothing and needs no maintenance." In the debate on the next generation of nuclear power reactors, reference is often made to the desirability of moving to inherently safe designs. Furthermore, such designs are often deemed to be associated with 'advanced' technology. Without entering into the debate on the various proposed manifestations of the concept that are currently in vogue, this paper points out that inherent safety has a long provenance in nonuclear applications.

Descriptions are given of examples of these applications, developed—as is too often the case—in the aftermath of major disasters. More recent developments in the chemical industry are reviewed and current proposals for transnational research in Europe are described.

AUTOMATIC CONTINUOUS TRAIN BRAKES

This is perhaps one of the earliest and wholly successful achievements of inherent safety in the form of designed failure to safety. The development—or at least its incorporation into legislation—followed the railway disaster at Armagh, Ireland, in June 1889. A passenger train was brought to a stand on an incline by lack of engine power, and the train was divided by the train crew. The trailing portion was held by inadequate hand brakes and, on being inadvertently shunted by the forward portion, ran back and collided with a following train. Over 80 people died. Shortly after, legislation was enacted in the UK requiring all passenger trains to be fitted with a continuous braking system held off by a vacuum provided by the engine. Any division of the train destroyed the vacuum and automatically applied the brakes on each vehicle. No human intervention was required.

INTRINSICALLY SAFE ELECTRICAL APPARATUS

Although the terminology is different, this application conforms to what is now called inherent safety and relates to apparatus for use in flammable atmospheres, such as can occur in coal mines and petrochemical plants. Safety is ensured because the electrical circuits are designed to be physically incapable of providing the currents and voltages necessary to generate sparks of sufficient energy to ignite flammable gas/air mixtures. A flammable gas/air mixture has a characteristic minimum ignition energy associated with it. An electrical circuit can be analyzed or tested to determine the energy that will be associated with the spark at any break in the circuit, whether occurring by accident or by operation of switches or other make-and-break contacts. An intrinsically safe design ensures that this latter energy is always less than the minimum ignition energy of the gas/air mixture in which the apparatus is to operate. The development of the concept was precipitated by the explosion at the Senghenhydd coal mine in Wales in 1913 in which 439 miners died. The explosion was caused by the ignition of methane by open sparking at an electrical signal bell. The development of the concept of intrinsic safety following that accident must be regarded as a classic endeavor in the achievement of safer working conditions in coal mines. It continues to be widely applied in any situation where electrical apparatus is required to continue to function safely in a flammable atmosphere. The application of the concept is governed by technical standards against which designs of equipment are independently assessed for compliance.

INHERENT SAFETY IN THE CHEMICAL INDUSTRY

In the explosion at the chemical works at Flixborough UK in 1974, the catastrophic failure of the connection between two reactors in a cyclohexane oxidation plant allowed up to 160 tonnes of flammable liquid to be released to the atmosphere, where it flashed to vapor and was ignited. The resulting explosion killed 28 people. The accident served to bring to attention the need to reduce the quantity of hazardous chemicals in a process, i.e., to make the process more inherently safe. In addition, the immediate cause of the accident was the failure of a metal bellows in the connection between the two reactors. The use of the bellows could have been avoided by using a longer pipe-run to provide the necessary flexibility in an inherently safer way, as indeed was the practice adopted in other similar plants extant at the time.

The importance of the Flixborough explosion in the context of this paper is that it marked a significant milestone in the evolution of safety in the chemical industry. It served to bring into prominence the need for inherent safety to be adopted as a design objective wherever possible and it also led to legislation to control the major accident hazards of the chemical industry in the UK and within the European Community (about which more later).

In the promotion of inherent safety as a design concept, a leading part was played by T. A. Kletz. In a series of papers, later incorporated into a monograph (2), he described many practical examples of inherently safe designs and described widely applicable general principles, ranging from reductions in inventory to substitution of nonflammable for flammable fluids. As a message to the chemical industry, Kletz adapted the Henry Ford dictum already quoted to the form 'what you don't have, can't leak.'

A good example of a reduction in inventory was the way in which the process for the manufacture of nitroglycerine was modified. The process involves the mixing of glycerine and acid. The modification replaced mixing in batches by mixing in a continuous flow, with a large reduction in the quantity in process at any one time. The flow of acid through a throat in a pipe served as a jet pump or injector, drawing the glycerine at a predetermined rate into the throat of the pump. The mixing ratio of the two liquids is

determined by the geometry of the pump, no metering devices being required. It is interesting to observe that the same simple principle was applied by Victorian steam locomotive designers in their use of the exhaust steam to induce a draught through the fire. The arrangement was entirely self-regulating—the faster the locomotive proceeded, the greater the exhaust blast, the greater the air flow through the fire, and in turn, the greater the rate of steam supply from the boiler. This principle continued to be used up to the end of steam power on railways.

Prior to the Flixborough explosion, there was a trend in safety design philosophy towards the 'Christmas tree' approach—the proliferation of add-on safety features. The analysis of the logic of these safety systems became increasingly complicated. The campaign for inherent, or intrinsic, as opposed to extrinsic safety was in part a reaction to this trend. It is fascinating that the nuclear power industry now appears to be sharing the feeling experienced in the chemical industry in the 1970s (3).

INTERNATIONAL COLLABORATION

One of the objectives of this Conference is to identify areas or subjects for international collaboration. Inherent safety has been offered as one possibility. The European Commission has already embarked on such an endeavor, again in the context of the chemical industry. The Commission has an established research programme on Major Technological Hazards. This is intended to support the practical application of the policies incorporated in the Commission's 'Seveso' directive, a legislative framework that had its genesis in the Flixborough explosion and the later accident at Seveso, Italy. The research programme includes inherent safety of chemical plants and processes in its remit, and the opportunity will be available later in 1989 for researchers within the member states of the European Community to bid for financial support for research proposals on inherent safety.

CONCLUDING REMARKS

This paper has attempted to show that the concept of inherent or passive safety is not new. Neither is it necessarily associated with advanced technology but rather with reliance on well-founded physical laws or principles. It would be a presentational error for the nuclear industry to allow the tag of 'advanced' to become attached to the concept—a tag that could well arouse the suspicion of the public, to the possible detriment of the case for the new generation of nuclear power reactors.

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COMMERCIAL SATELLITES AND NATIONAL SECURITY*

by

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On February 21, 1986 SPOT 1, the first SPOT satellite, was launched from Kourou, French Guiana on an Ariane 1 rocket. Two months later, on May 1, SPOT 1 acquired imagery of the Chernobyl Nuclear Power Plant in the Soviet Union following the nuclear accident. These images, otherwise commercially unattainable, were used by the international news media to cover the event. By 1988, SPOT's ground resolution was nine times better than other civilian systems, capable of providing ten meter resolution images that can reveal roads and other linear features significantly narrower than ten meters.

We are clearly witnessing a revolution in communications technology, of which the commercial availability of remote-sensing satellites is one dramatic manifestation. The question to be addressed in this paper is the following: What will be the likely effects of the information provided by these satellites on governmental decisions (especially the US government) related to national security in general and crisis situations in particular?

Although the public debate on this issue is only in its infancy, two perspectives, diametrically opposed, are already beginning to take shape. The first—the revolutionaries—conclude that high-resolution commercial satellites have irrevocably broken the monopoly of remote-sensory information held until now by the United States and Soviet governments. With many players likely to gain access to this information, the ability of the superpowers to conduct classical crisis decision-making in secret will be lost forever. Relations with allies will consequently become far more complex and the role of the news media will be even greater than at present in influencing governmental and public perceptions of international events.

The second perspective—held by the traditionalists—is highly skeptical of the conclusions of the first. Those holding this view argue that Washington and Moscow, and a few other major governments to a lesser extent, possess a multiplicity of intelligence sources that far exceed the capabilities of commercial satellites. These include (1) numerous satellite systems with greater photographic resolution than offered by SPOT and its commercial competitors (less than five meters); (2) an ability to recover information much more rapidly than commercial users, thereby having a great advantage in access to time-urgent information of vital importance in a crisis; (3) the availability of a large variety of other electronic intelligence sources (including land-based, sea-based, and air-based communications monitoring systems); and (4) access to a substantial network of human intelligence sources that are able to corroborate, refute, or modify information gathered by other means and to obtain information that cannot be acquired by electronic devices. In short, the traditionalists hold that governments in general, and the United States and Soviet governments in particular, will continue to enjoy a large advantage over all other interested parties in both the quantity and quality of information available. The conclusion that follows is that information obtained from commercial satellites will have relatively little effect on the behavior of governments because the intelligence communities will continue to enjoy a huge advantage in receipt of accurate and timely information. Both because of their access to a multiplicity of sources and their ability to employ highly sophisticated professional personnel to interpret the data received, governments will have far greater confidence than commercial users in the conclusions to be drawn from the information acquired.

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* Based upon work originally undertaken for the Commercial Observation Satellite Project of the Carnegie Endowment for International Peace

In assessing the accuracy of these two perspectives, and of intermediate positions, uncertainties abound. Commercially-available communications technology is being revolutionized and no one can say with high confidence today what quality of information will be available in five or ten years, at what price, and in how timely a fashion this information will be retrievable. Who is in a position to judge with great accuracy how capable will be commercial users of this information to analyze and fully appreciate the data they have "retrieved?" Moreover, the true capabilities of the United States and Soviet intelligence communities, both "sources and methods," are among the most closely guarded secrets possessed by these governments. Hence, any assessment of how rapidly government will stay ahead of the commercial sector in this field is primarily conjectural.

To probe this subject constructively it is therefore useful to look not at the technologies but at the structure of national security decision-making, specifically in crisis situations. Once we have a better feel for the characteristics of crises we can begin to offer at least tentative judgments as to how improved commercial observation satellites might affect their outcome.

HOW DO WE KNOW A CRISIS WHEN WE SEE ONE?

Officials in the United States and the Soviet Union make thousands of decisions daily. It is not the purpose of this paper to address the day-to-day routine of government. Rather the focus is on those special events labelled "crises." What differentiates a crisis from a non-crisis? Despite the voluminous literature on crises and crisis decision-making, there is no single, clear answer dominant in the literature. There are however a set of characteristics that are prevalent in crises which tend to differentiate them from "business as usual."[1] These may be summarized as follows:

1. It is felt by key decision-makers that time is short. It is sometimes said that for top-level decision-makers in government, especially in the national security arena, the "urgent crowds out the important." Most of the time senior officials are moving from one major issue to another and have relatively limited time to plan or think conceptually about the foundations and basic premises of the policies that have been adopted. But still it is relatively rare when the decision-maker concludes that urgent attention needs to be allocated to one particular issue, that it cannot be delayed even a day or two, and that it must take precedence over all other concerns, no matter how important everything else is.
2. The value of specialized expertise rises dramatically. It is consistently the case in crises that information not normally thought of much value becomes suddenly of crucial importance. A fine example was the taking of the American hostages in Iran in November 1979. One of the first considerations in Washington was the effort to "guess" as to the likely location within the US Embassy in Tehran where the hostages might be held. In order to make the best guess a floor plan of the embassy was required. It turned out that no floor plan was available in Washington, thus hindering initial efforts at crisis management.[2] This characteristic is especially relevant to our topic. If specialized information of great significance can be obtained from observation satellites, those in possession of such information can have an important impact on the conduct of the crisis. As the example above reminds us, however, there is a good deal of crucial information that may be required which no satellite could provide.
3. Ad hoc groups are legitimized to deal with the special situation. We know we are in a crisis when routine channels of communication cannot suffice and extraordinary groups must be created whose

life spans only the duration of the crisis. The famous ExComm established by President Kennedy to deal with the Cuban Missile Crisis in October 1962 is a case in point. A Crisis Management Group was established by President Carter as a contingency plan after the fall of the Shah in February 1979 and was activated once the hostages were taken in November of that year.

4. A small number of players tend to assume responsibility for evaluating on-going events. In the United States government, authority over virtually all policy issues is intrinsically fragmented, often cutting across the lines of several major departments of the executive branch and affecting the agendas of a number of Congressional committees and subcommittees. To resolve a routine policy problem, therefore, it is not unusual for scores of individuals to be involved. In a crisis, on the other hand, there is a tendency to "circle the wagons" and limit access of information and decision-making participation to as small a group as possible. No one not considered essential to resolving the crisis is admitted into this inner circle. Indeed, there are often circles within the inner circle. For example, during a key moment of the Cuban Missile Crisis when Robert Kennedy was asked by President Kennedy to meet with Soviet Ambassador to the United States Anatoly Dobrynin to discuss a letter that President Kennedy had received from Premier Nikita Khrushchev. Evidently key members of ExComm including Paul Nitze and Maxwell Taylor were kept in the dark about the meeting.[3] In general the greater the effort to circumscribe access to the decision-making process, the more acute the crisis.

5. There is a strong sense that the decisions taken carry great significance. What is particularly noticeable about a crisis is that those involved believe that they are at a "crossroads," that the decisions taken will have enormous precedential value, that what they do today will be of importance not merely to resolve the issue at hand but because it will influence greatly the course of future events.

6. The crisis is seen as a turning point leading to improved or worsened conditions. Similar to the point raised as above, there is a strong feeling among the participants in the crisis that things will "never be the same" after the tension has subsided. There is a feeling that one cannot stand pat or return to the status quo ante. Rather, decisions made during the crisis will define the future environment once the crisis has receded.

7. Crises are opportunities for some to achieve goals that were denied to them under normal circumstances. While there is a natural human instinct to fear a crisis and to have an "avoid the mine fields" and damage limitation approach while passing through it, this is not a view that is universally shared. Some see a crisis as a window of opportunity; they seek to exploit the conditions established by its emergence rather than merely working to diffuse it and avoid catastrophe. One example of this behavior is the actions of Minister Ariel Sharon at the time of the assassination of the Israeli Ambassador to Great Britain in the spring of 1982. Sharon had long argued for the need of an Israeli invasion of Southern Lebanon but had been constantly rebuffed by Prime Minister Menachem Begin and other members of the Israeli Cabinet. However, after the assassination political attitudes changed dramatically in Israel and Sharon was able to gain the approval for the invasion that had long been denied. This suggests that "crisis manipulation" to achieve the most favorable outcome for one's self, one's department, or one's nation can be as important as "crisis management" which tends to imply more of a group commitment to a risk aversion strategy than is actually shared by all the key decision-makers.

Unless one is clairvoyant it is extremely difficult to anticipate a crisis in advance. No matter how detailed has been the contingency planning, the complex world of international politics is such that crises often seem to "pop up where they are least expected." But decision-makers do not wish to have to wait to

read the headline in the Washington Post that the government is in crisis in order to adopt special procedures to deal with it. On balance, the more these seven characteristics are present, the more the condition that one is faced with can truly be termed a crisis situation. Now let us turn briefly to the historical record of crises in the history of US national security policy-making.

TELESCOPED VERSUS PROTRACTED CRISES

By far the most analyzed and talked about US national security crisis since World War II is the Cuban Missile Crisis, partly because it was thought to be the closest we have come to a Soviet-American nuclear war, partly because of the fascinating personalities involved in crisis decision-making, and partly because of the wealth of material available to scholars including the memoirs of Robert Kennedy and Theodore Sorenson.

Several interesting characteristics of this crisis are worthy of note, some of general value, and others very germane to this set of events. These may be summarized as follows:

1. The crisis was triggered by a discrete event—the emplacement by the Soviet Union of nuclear missiles in Cuba. This event defined and immediately transformed the decision-making environment to a crisis mentality.
2. Knowledge of the deployment of the missiles was obtained through sophisticated photo reconnaissance techniques then available solely to the United States government.
3. A special group—ExComm—was established to conduct the entire decision-making process. The President participated frequently, but not always, in the deliberations of this body. There were evidently no leaks of information from this body to external sources.
4. Despite this extraordinary control of the decision-making process, a number of key actors were involved at various stages of the crisis who were external to ExComm: a French diplomat in Cuba who learned of the deployment of the missiles; President Charles DeGaulle of France who supported President Kennedy during the crisis; Senator Kenneth Keating of New York who sought to gain politically by announcing that Soviet missiles were in Cuba; Colonel Oleg Penkovsky, a high-level Soviet official who was working secretly for the US Central Intelligence Agency and assured the United States at a key moment in the crisis that Soviet missiles in Cuba were not ready to be fired; John Scali of ABC News who was approached by a senior official in the Soviet Embassy in Washington in an effort to diffuse the crisis; and Max Frankel and his associates at *The New York Times* who learned of the decision to "quarantine" Cuba but who were persuaded by President Kennedy not to publish the information until the President had told the nation and the world of his decision.
5. The crisis had an abrupt beginning and end with a total elapsed time of only thirteen days.

We may consider this to be a "telescoped" crisis, referring to the short compression of time in which the entire matter was played out. Yet even under these very special circumstances it is interesting first to note that a large number of players outside ExComm could have intervened at various times to thwart the crisis management effort of the Kennedy Administration if they had chosen to do so. None of them did—an amazing record that one could not count upon to be repeated. Participants who became involved at one point or another included members of Congress, political opponents of the President, allied governments, newspaper and television journalists, and a US businessman visiting Moscow, among others.

Another interesting feature of this crisis is that despite all we knew, or think we knew about the crisis, including the candid recollections of many of the participants, a recently declassified transcript of one day in the life of ExComm has significantly altered our understanding of key aspects of the decision-making process.[4] The transcript revealed that

- President Kennedy was ready to trade the removal of missiles in Turkey for the removal of missiles in Cuba rather than go to war.
- There was no acrimony among the ExComm participants at the moment of crucial decision.
- Secretary of State Dean Rusk was lucid and an important participant during the crucial deliberations on October 27.
- There were no detailed discussions of military contingency plans toward the Soviet Union on this day of the crisis.
- Neither domestic, political considerations nor bureaucratic rivalries played a significant role in crisis decision-making.

Each of these points runs counter to the conventional wisdom about the conduct of the crisis. It was thought, prior to publication of the transcripts, that Kennedy was willing to risk war to have the Soviet missiles removed and rejected proposals for a trade over the Jupiter missiles in Turkey; that there was great acrimony and harsh disagreement among the principles at the end of the crisis as the prospects of nuclear war loomed large and fatigue overcame the principal participants; that Dean Rusk had become incapacitated under the strain of the crisis and was not involved in key discussions at its climax; that military contingency plans had been discussed in detail by ExComm since war with the Soviet Union seemed imminent; and that bureaucratic rivalries and domestic political considerations both heavily influenced the posturing of members of ExComm and shaped the character of its decisions. These are crucial points, not only to set the record straight about what actually occurred during the Thirteen Days, but because they tell us that our actual knowledge of crisis decision-making may be far less certain than we had thought it was.

If we examine the national security policy-making process of each administration since President Kennedy's, what is even more striking is the absence of telescoped crises. There were specific moments when actions were deliberated under extreme tension—when Khe Sanh in South Vietnam looked like it might fall in 1967; when Soviet forces invaded Czechoslovakia in August 1968; when President Nixon decided to bomb Hanoi in 1972, among others—but none had the discrete qualities of the Cuban Missile Crisis. Rather, what are far more prevalent are protracted crises—extremely difficult situations that build slowly over time, that have no immediate resolution, that involve large numbers of individuals outside the American government, and that may take months or longer to resolve. Many of the most significant national security crises facing American Presidents, especially in the last decade, have dealt with the political stability of authoritarian regimes friendly to the United States. President Carter was faced with a major protracted crisis in the fall of the Shah of Iran which played itself out from January 1978 through January 1979, only to be followed by the Hostage Crisis which consumed his attention from November 1979 through January 1981. He was also in a protracted crisis during the fall of the Samoza regime in Nicaragua and in the formulation of a policy toward the successor Sandinista regime in the summer and fall of 1979. President Reagan experienced a major crisis during the fall of the Marcos regime in the Philippines which became severe in the fall of 1985 but did not subside until Marcos left the country in February 1986. More recently, the Reagan administration had a major crisis over the attempts to oust General Noriega of Panama, an experience that continued throughout the spring and early summer of 1988.

The characteristics of protracted crises are different in important respects from those of telescoped crises. First, no single event automatically triggers the crisis. There is instead a gradual buildup of negative developments involving an increasingly larger group of high-level policy-makers who slowly but surely begin to put other things aside to pay more attention to the emerging crisis. Second, because of the lengthy duration of the crisis there is a much higher probability that all sorts of constituents will become involved. The ability to circumscribe participation in the crisis decision-making is much more difficult as the crisis continues unabated. Third, a wide variety of information is potentially relevant to the crisis and its resolution. As a consequence there is much more "noise" from which to identify the true "signals" relevant to the events at hand. This point is graphically illustrated in Gary Sick's detailed account of the Carter administration decision-making involving both the fall of the Shah and the hostage crisis. With respect to the hostage crisis Sick noted:

> Throughout the crisis, there was the problem of distinguishing genuine messages and interlocuters from those who were self-appointed "messengers of good will," entrepreneurs seeking to turn the crisis into fame or fortune for themselves, or representatives of a political faction among the many in Tehran.[5]

Sick described in extensive detail how different groups within Iran, various European governments and individuals, the Algerian government, and others all sought a role for themselves in the resolution of the crisis. In Sick's account, moreover, there are numerous examples of how specialized information played a key role. For example:

- The hostage rescue mission was never fully practiced in the United States for fear that it would be detected by the press and lead to aborting the mission. Sick defended this on the grounds that "the US experience in keeping secrets—even in matters of the most sensitive military security—is exceptionally poor, and thus mission planners had good reason to be wary." In retrospect, it has been claimed that the failure to conduct such an exercise hampered the ability of the rescue team to anticipate problems they subsequently encountered.[6]
- At a key point in the crisis over the fall of the Shah it was decided to redeploy US naval forces based at the Philippines to the Persian Gulf. A seaman on board one of the ships telephoned his mother in Nebraska prior to the redeployment and informed her of his ship's new destination. This information was ultimately obtained by a stringer for one of the wire services who lived in the seaman's home town and very soon thereafter all the major news networks were reporting the imminent deployment before it had even commenced!
- It will be recalled by most Americans that the television program "Nightline with Ted Koppel" was first launched during the hostage crisis. Koppel conducted many interviews with key personnel in Iran during the crisis to whom the US government did not have access. Ultimately, the continuous countdown of the hostage crisis, performed nightly by Koppel for almost one year, was a major factor in influencing President Carter's decision to attempt the hostage rescue mission.

In subsequent discussions Gary Sick has noticed several characteristics of the Iranian affair worth reciting: that decision-makers bring intellectual, political, and psychological baggage to a crisis in the the form of deeply rooted beliefs that greatly influence their behavior; that because of information overload it is very difficult to sort out what is truly important; that, ironically, despite the plethora of information it is still "imperfect" and never quite provides the decision-maker with everything that is needed to resolve the crisis; that in a protracted crisis there is extensive bureaucratic infighting and paranoia among the key

participants; that leaks are inevitable; and that covert channels of contact abound making it difficult to know exactly who knows what and when. Sick has argued that unlike the Cuban Missile Crisis, which teaches us that a crisis is like a chessboard, his experience for four years dealing with Iran on the National Security Council Staff suggests that a crisis is like a hurricane. The former has defined players, relatively clear cut options, but a bewildering array of possibilities that make it difficult to see many moves in advance. The latter is totally unpredictable, its direction and intensity can change markedly and without warning, and there is no simple means by which one can gain one's bearing in order to seek shelter.

COMMERCIAL SATELLITES AND CRISIS DECISIONS

If one accepts the notion that future presidents are more likely to face protracted crises of the Iranian variety than telescoped crises like the Cuban Missile Crisis, there are important implications for the way in which commercial observation satellites will influence the course of events. First, a large number of players—much larger than the number authorized by the President—would seek to play a role in shaping the outcome. If it were up to the American President, as was illustrated in the Cuban Missile Crisis, the players would normally be limited to selected participants from the Departments of State and Defense, the National Security Council Staff, the Joint Chiefs of Staff, the Central Intelligence Agency, perhaps key members of the Congressional leadership, and, depending upon personal relationships, the Attorney General and the Secretary of the Treasury. The President would hope to be able to limit the transmission of policies determined by this group to the most senior officials of the potential adversary and possibly to a few of the most trusted allied heads of state. In the real world of contemporary crises, such as the ones experienced by President Carter and Reagan, the situation is very different. One is not dealing with a "potential adversary" but a friend who at some point may become an adversary. Because a large number of political and diplomatic moves are an inherent part of these protracted crises, information normally limited to the intelligence services could be obtained by a wide variety of sources in a world with a plentiful supply of high-resolution commercial observation satellites. These satellites therefore provide a ticket of admission for nongovernmental actors and other noncentral governments to participate in the unfolding crisis. Information sources would tend to multiply and crisis control by the United States or other central players would become extremely difficult. The potency of the noncentral players would be proportional to the timeliness of the information they could contribute.

The number of noncentral players that could tend to shape a crisis could truly be startling: political opponents of the US President; bureaucratic opponents of key central players; governmental adversaries of the United States (both those centrally and not centrally involved in the crisis); nongovernmental groups in the United States and other countries seeking to benefit from the turmoil of the crisis or from a preferred outcome; allied governments not invited to participate by the central players; opponents of allied governments seeking to embarrass them; print, radio and television journalists from all over the world (recall that the entire Iran/Contra affair was brought to world attention by a leak in a Beirut newspaper about clandestine US-Iranian negotiations concerning the release of the hostages); criminal elements; and even mentally deranged individuals who have the economic resources and presence of mind to take advantage of information provided by the commercial observation satellites.

Second, the introduction of such a large number of players, or potentially large number of players, would not only greatly increase the quantity of information introduced during the crisis but would make it exceedingly difficult to separate the wheat from the chaff in order to ascertain who provided what to whom. The net effect would be a complicating of the crisis management process.

This does not mean that all crises from now on will become three ring circuses largely spinning out of control. Should Mr. Gorbachev seek to intervene in Eastern Europe to squelch dissident movements or should India redeploy forces to ready for renewed hostilities with Pakistan it is highly likely in the near-term that this information would first be in the possession of the United States and the Soviet Union. A classical telescoped military confrontation involving short mobilization times would probably be least amenable to influence by the information that ordinary citizens could obtain from commercial satellites. The shorter the crisis the less time for other players and other information to enter the decision-making process. And, for some years to come, presumably the major intelligence services will still dominate both the quantity and quality of information that could be meaningfully brought to bear to shape the outcome of the crisis. Moreover, a growth in the number of individuals and governments with access to such information surely increases the likelihood that this information would be made public. Once this occurs and the transparency of the intentions have been revealed, the likelihood of aggressive action being undertaken would probably be reduced. If one believes, for example, that aggression is often coupled with surprise and that surprise is thwarted by transparency of intentions, then the increased availability of observation-satellite photography would reduce the likelihood of aggression even if it complicates crisis decision-making sometimes in unhelpful ways.

The problems faced by democratic societies would appear to be especially acute in a world of plentiful commercial satellites. Major issues of first amendment rights, freedom of the press, and executive-congressional relations—to name just three—would collide with national-security considerations. Substantial legal and even moral issues would be joined with major foreign-policy considerations. Jurists and philosophers would have a legitimate role to play in sorting out the entangled relationships derived from the citizen's right to use information that could, under certain circumstances, jeopardize the national security.

Of course it could be argued that private sources could tend to confirm governmental policies and build consensus within the society rather than tear it apart. However, except under the most extreme circumstances (such as a seemingly imminent attack on the territorial homeland) there is little likelihood that private sources would seek to bolster official policies. In the United States, for example, there are two major factors at work. First, the foreign policy consensus that was generally in place from the end of World War II through the mid-1960s still has not been rebuilt. Even basically positive experiences of the Reagan administration in foreign affairs have failed to heal the wounds of Vietnam. Therefore, no matter who is in power in the White House, it is difficult to envisage that powerful opponents would all foreswear from using available information to thwart the policy objectives of the executive branch. Second, the compact (pact?) between the press and the White House was also shattered in the 1960s and early 1970s. The press is now not only in an adversarial role vis-a-vis the administration but seeks to become a central element of the policy-making process. Newsmen are newsmakers, and the more access they have to sensitive information the more potent they will be in the shaping of policy. Moreover, competition within the news fraternity is now so intense, the financial stakes are so great, and the corporate backers of the major news organizations are so profit-oriented that even if particular journalists sought to refrain from using "scoops" they cannot do so for fear that their patriotism could cost them their jobs.

The decision-making processes in the Iran rescue mission cited above indicate that even fear of leaks could jeopardize or at least influence the conduct and frequency of military operations. It has been noted, for instance, that the hastily planned US invasion of Grenada, in which unnecessary casualties were taken, was rushed to avoid any participation by the press in the actual operations. The lesson that the Reagan administration had learned from both the Vietnam War and the bungled Iran Hostage rescue mission was: cut the press out until victory is achieved. But the Grenada operation was very special—in close geographical proximity to major American military forces who encountered only token resistance. All things considered, these are almost ideal conditions and still the operation was not error-free. Once one considers major military operations far from American shores likely to encounter substantial opposition, it is difficult to see how military secrecy can be securely maintained.

A further complication that we now only dimly understand is the impact of such technologies on third-country governments, especially those with limited intelligence services of their own. We know, for example, that as the Falklands/Malvinas crisis developed, the Argentinean government utilized information about British naval deployments provided by both Spanish and Italian sources in formulating its national policies. Whereas the traditionalists may be right in the short term about the United States—its intelligence sources will stay substantially ahead in capability of what is commercially available—the impact on third country governments may be very great indeed.

What we are considering here is the plausible impact of new technologies on public policy. We know from past history that technological innovation has unpredictable consequences for societies and for the conduct of warfare. Among the interesting historical patterns are these:

1. There is a constant struggle for military advantage through the process of measure-countermeasure-countercountermeasure in military technology. This process defines contemporary military competition as it has defined it since the age of the cave man.
2. Technological innovation is often resisted by military organizations who have a vested interested in the weapon systems and procedures they adopted long ago.
3. Revolutions in the art of warfare sometimes occur from non-revolutionary adjustments of military technology or tactics (e.g., the tank, the levee en masse).
4. Many times students of military technology thought they had come across the "absolute weapon" only to find it superceded by a new technological development.[7]

The introduction of high-resolution commercial observation satellites will almost certainly have unanticipated consequences. It is foolish to write them off either as irrelevant to national security decision-making or as revolutionary. In the case of sea power and air power there were prophets ahead of their times who saw tremendous implications for these new technologies—sometimes less than were ultimately realized but certainly more than allowed by the initial group of skeptics. Similarly, with respect to commercial satellites, thinking hard about these unanticipated consequences from diverse national and sub-national perspectives is a prerequisite to a sound appreciation of their significance.

ENDNOTES

1. Michael Nacht, "Public Management: Does It Exist? How Do You Do It?" in Lecture Notes in Economics and Mathematical Systems (Berlin: Spriner-Verlag, 1983), pps. 41-50.
2. Gary Sick, *All Fall Down: America's Tragic Encounter With Iran* (New York: Random House, 1985), pps. 205- 216.
3. David A. Welch and James G. Blight, "An Introduction to the ExComm Transcripts," *International Security*, Winter 1987/88, pp. 16.
4. "October 27, 1962: Transcripts of the Meetings of the ExComm," *International Security*, Winter 1987/88, pps. 30-92.
5. *All Fall Down.* pp. 359, footnote 1.
6. *All Fall Down*, p. 297. This point was also emphasized in a conversation between the author of this paper and Lt. General John Pustay, a key figure in the military planning of the operation.
7. Michael Nacht, "The Age of Vulnerability," (Washington, D.C.: The Brookings Institution, 1985), pp. 55-57.

SOME POLITICAL PROBLEMS ON GLOBAL CLIMATE CHANGE

by

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The state of human capabilities on predicting, and possibly modifying, our weather and climate does not lend itself to easy generalization. It is still typical for the man on the street to scoff at most of meteorology, ticking off all the times when the weather forecast seemed to be wrong and when the Farmer's Almanac was allegedly right. Such spurious folklore aside, however, tremendous strides have indeed been made in weather analysis and weather prediction, by the harnessing of satellites and computers and the simple accumulation of scientific knowledge.

With this ability to predict future weather has also come a better understanding of man's impacts thus far on climate and weather and hence also the possibilities now of a deliberate, rather than inadvertent, modification of this climate; and with this can come a host of new political conflicts. Whenever man understands a linkage, he can then be deliberate about it; when he can be deliberate, he gets into new arguments.

IMPACT AND CONTROL

With regard to deliberate modification of climate, some definite successes had already been achieved on a more local or microcosmic level for four or five decades, in the artificial inducement of rainfall and the clearing of fog. Such success stems from the exploitation of local catalytic or "triggering" effects in which a small input of material or energy induces changes of much larger magnitudes in the weather. Not so surprisingly, even such first minor uses of weather-modification techniques have then brought an aftermath of numerous lawsuits within the domestic courts of the countries involved.

These might then set the stage for grander suits and disputes at the international level, once larger projects are undertaken. At the grander macrocosmic level of impact on weather or climate, the bulk of analysis thus far has been addressed to the inadvertent impact of man's ordinary activities on earth. Yet the likelihood of international resentment and litigation is not confined to the use of techniques deliberately shaped for the modification of the atmospheric environment. There may be similar responses to all the more ordinary measures taken, or not taken, by any causally significant state, simply because the world will have more accurately identified and understood the major causal linkages involved.

For a firm or city in the United States to affect the acid content of rainfall in a district downwind in Canada might thus have drawn less resentment in the past, not because the American city did not have the capability to alter its climactic contribution forty years ago, but because no one on either side of the border would have had such a clear theory on the connection. Today, with the responsibility and resentment that better information brings, things may be quite different.

A much more major example is now emerging with analysis by which the undeveloped jungles of Brazil amount to a major resource for all mankind. Brazilians might note that there was once much more in the way of green zones scattered all around the globe, such that the jungles of the Amazon were not then so indispensable for the elimination of carbon dioxide. Other countries "developed" their green areas

just as Brazil would now like to develop the Amazon basin, but the other countries got away with doing so before any advanced ecological theories had been raised to object to the process.

Will the governments of the outside world now be prompted to protest about what the government of Brazil does with its own land, given that what it does will affect the future carbon-dioxide levels in the air that passes over that land and the land of other states and, hence, can accelerate a global warming? Is the holding back of a social good the same as the imposition of a social cost? As with everything else in the world of law and international law, much will depend on the base line from which one wishes to reassure what is "reasonable."

PRECEDENTS OF CAUSALITY AND CONFLICT

Man had undoubtedly changed his climate even earlier, in many cases inadvertently and perhaps destructively. Yet, as stressed above, our experience with any political tensions connected with such changes will have to be drawn from a narrower range of impacts, those that were anticipated at the time the decisions were made. How many cases do we have in history from which to begin collecting precedents—cases of government officials, and the public at large, actually expecting some impact on the weather and climate? And what were the theories of law and compensation and responsibility such precedents seemed to endorse?

It would indeed make little difference if the theory of atmospheric side effects held at any earlier time was wrong, i.e., if the feared impact on the climate was not going to materialize in reality; even a wrong-headed anticipation of social goods and social costs would give us some clues here on the likely development of international law and international practice.

It apparently was widely (and wrongly) believed, as the American pioneers moved west, that "rainfall follows the plow." This would of course have been the kind of weather-modification theory that generated relatively few legal entanglements. By plowing up the great plains, the farmer was developing a need for rain, but he was allegedly in the same process answering the need, finding his own water, with no clear negative side effects for anyone else and no clear drain on anyone else's water supply. While this may have simply been some kind of wishful-thinking folklore, it presumed a sort of impact from ground to air.

Much of what one might ever fear, or hope for, in climate modification would come from substantial alterations of the flow of water bodies. One apparently thus had anticipations that either the Suez Canal or the Panama Canal might alter water temperatures and water flows in ways that generated climactic side effects. Given that the Panama Canal involved locks that precluded the flow of water from ocean to ocean, this may all strike one now as very shabbily done scientific prediction indeed. Yet the canal was indeed a larger human engineering project than any that had been undertaken before, and we might here just have been encountering an elementary intuitive caution that is not so badly taken, that large projects may always be somewhat unpredictable in their side effects. (The canal may well have had a local climatological impact on Panama itself, in the process of creating a large lake in the center of the Panama Isthmus as part of the canal system.)

The decision some years later to extend a railroad from Miami to Key West brought some expressions of concern that the warm flow of the Gulf Stream's waters would be slowed or impeded, thereby cooling Britain and Europe. In truth, no such effect occurred. At the same time, it is interesting that construction of the bridges went ahead despite the predictions made, that no European navy was dispatched to interfere with this possible menace to the climate and health of the European continent.

One might similarly have expected some local climatological impact from the Dutch decision to convert the salt-water Zuider Zee into the fresh-water Isjel Meer and to drain part of this sea into dry-land Polders. Again one sees no concrete international objections to this substantial change in the status quo. Dutch spokesmen might of course have responded that they were only restoring what had been dry land at the time of the Romans; whether or not one dates his rights and properties from the bequest of that Empire, the more probable explanation for the absence of objections would have been that most of the climatological impact from the drainage and change in the sea would have been thought to be confined to the Netherlands itself.

One clear forerunner of what could be a great sensitivity to tampering with "what nature gave us" comes with efforts to reduce the intensity of hurricanes and/or to change their course. Given the imperfect understanding we still have of such phenomena, it is always possible that an effort to diminish wind strength might actually and inadvertently increase it, or that an effort to steer it west would actually push it east. This would fall into an always irreducible residual category of the risk of unintended impact, of bad meteorological practice, or of overrating one's competence. Lawsuits at the domestic level, and possibly more bitter responses at the international level, are altogether likely to follow when such fiascos occur; even a reasoned argument that a certain technique had a four-in-five chance of working as intended is not likely to appease the critics or to head off the lawsuits.

Possibly even more worrisome, however, are the disputes over intended consequences when the techniques indeed have the predicted impacts on hurricanes. Everyone involved presumably shares an interest in reducing the wind intensity of such storms, but what if the only scientific way to do this is to steer them across some unfortunate small Caribbean country? Or what if there is a clear tradeoff between the risk of a given storm hitting South Carolina or hitting the Bahamas? Here the issues would not have been questions of competence but of comparative national power and competing national interests.

At least one such "real-life" issue has come to light, in the charges of some Mexican radicals in the 1960s that United States experiments had deliberately or inadvertently caused a hurricane's course to shift so as to damage Central America.

A TYPOLOGY OF SITUATIONS

To set up a rough-and-ready topology of cases, one might thus consider an array as follows in which country "A" in the left column holds the actual capability on its territory to influence the climate pattern of both and in which the numbers roughly indicate the benefits and costs to the two sides of the actions proposed. A positive number in column "A" thus indicates that the country making the crucial causal input for a change in weather or climate derives a positive output in return, whereas a negative number under "B" would indicate that the country having no control over what is being done is somehow losing thereby.

	A	B
I.	+3	+3
II.	+3	+1
III.	+1	+3
IV.	+3	-1
V.	+1	-3

VI.	-3	+1
VII.	-1	+3
VIII.	-1	-3
IX.	-3	-1
X.	-3	-3

The first two of these cases would seem to be relatively litigation-free (assuming always, of course, that the predicted returns are indeed going to be the actual returns, with no unanticipated ecological disasters emerging as a result of the climate impacts undertaken). The major actor in the modification is also the major beneficiary. The other affected state comes out ahead as a result of the process.

The third case might begin to bring tensions to the surface, however, since the country whose territory and airspace and efforts are required and utilized for the modification is no longer the major beneficiary but rather would have to watch the bulk of the improvement land on the country downwind from the causal impact. Here a temptation would inevitably emerge to bill the recipient country for the services rendered; at the very least, they might seek to recover the costs of the climate modification project, but it probably would go beyond this, to tax the users for their benefit from someone else's natural resource. If the Arabs can charge for the use of their oil from under their territory, why could not a country controlling the future of someone else's climate from over its territory charge whatever the traffic will bear on this?

From charging "whatever the traffic will bear," the analogy with Arab oil producers obviously could slide a little further along, to get into the political uses of such modification. If Canada were one day to disapprove of the policies of the United States on some issue, could it threaten to impose an embargo of climate services, threatening to shut down whatever facilities in British Columbia had been playing a crucial role in moderating United States weather?

The U.S. Congress and public seem agreed today that agreements should be reached forbidding the waging of war by means of weather modification. This presumably means that countries would abstain in wartime from worsening each other's weather and climate, at least as compared with what nature had rendered in the first place. Yet our discussions here of a positive climate modification then raise an obvious question. Would it be weather warfare for a nation in wartime to cease improving its adversaries' weather? What if the climate help had been going on for decades, and the recipient had become dependent on it, letting his flood barriers slip in the process?

The fourth case and the fifth case obviously pull us much more directly into the issues of litigation that many foresee for the future. What if the state with the indigenous capability for climate modification benefits greatly or marginally from this and imposes marginal or great suffering on other countries? Where the gains are great on one side and the costs are marginal downstream (as in case IV), the human race comes out ahead in the net, and the beneficiaries ought to be able to compensate the sufferers. But will they? Where the results are the reverse (as in case V), the human race comes out a loser in the net, and the project ought to be discouraged and vetoed by some sort of international decision process. But will it be?

The fifth case might now seem the easiest to handle, with all of its obvious analogy to water pollution and other forms of ecological disruption in ordinary international dealings. If France and Italy can somehow come to terms on the control of water pollution along the Riviera, the analogy to climate modification ought to be transferable easily enough. But will the atmosphere really lend itself so easily to rules analogous to those applying to Lake Erie?

The sixth case would seem relatively easy, since the nation with the controlling position is not likely to impose great harm on itself, merely to offer small gains to a neighbor. But the political handling of the seventh kind of case would thus be more worrisome, because it is presumably the kind of climate modification that we would indeed like to see physically implemented, given the expected pattern of net benefits. Why would it not be possible for the downwind beneficiary in this process to agree to compensate the upwind source of the benefits, since the gains for the beneficiary are so large? Why would it not be possible for the beneficiary to commit itself to such compensation?

A large part of the difficulty here lies with the long-term credibility of compensation. Any states agreeing to be slightly disadvantaged by a pattern of climate modification are agreeing to something that may well go on into perpetuity, which may soon enough come to seem indeed like the new "natural order of things." Whatever the sincerity of the recipient state in promising to deliver compensation, perhaps in straightforward cash payments, there is a tendency for time to corrode the memory of the legitimacy of such compensation and/or the financial value of it. A good analogy can be found in the reluctance of Canadians to sell their water resources to the United States, as compared with their ready willingness in the past to sell oil from Alberta. Since water, unlike oil, is a nondepletable resource, the passage of time might simply lead people to forget that the water ever flowed on any other track than from Canada to California (as they have forgotten that it did not always flow so "naturally" from Arizona to California). Time might similarly lead people to forget what the climate used to be like or how the air used to flow.

The only easy way to compensate for such a major shift in the flow of a nondepletable resource (which hence can look "permanent" and "natural" in its new path) might be to match it with a compensating permanent shift of a comparable resource in the other direction. If the United States agrees to a permanent minor loss in climate patterns to improve Canada's climate significantly, it might be persuaded to accept this by a permanent increase in its water flow from Canada, of a form slightly harmful to Canada and very beneficial to the U.S.

This is all a little like the difference between giving the residents of an American Indian reservation an appropriation of money for some years into the future or giving them a hydroelectric project immediately next door. The latter is a permanent, nonfungible, nonremovable concession, one that they can trust to remain in place no matter what changes come in politics, no matter what inflation comes in the monetary realm. As such it is a more meaningful concession.

Agreeing to changes in climate tends to resemble such a more permanent and meaningful concession. Unfortunately, the normal means of inter-nation compensation tend to resemble the less reliable and permanent cash payments. One form of the international problem is thus going to arise simply in finding the logical matches of kinds of concessions here.

We have thus far considered cases of climate modification in which both sides presumably benefit or in which at least one side benefits. Cases in which both sides lose in such modification (our cases eight, nine, and ten) may seem so bizarre as to rule themselves out of consideration; but they come back to life when we move along to consider the equally bizarre general human activity of warfare. We certainly may encounter situations where a power might be inclined to achieve nothing for itself in climate or weather modification or might even be willing to hurt itself some moderate amount, only because it was thereby hurting an adversary a seemingly large amount.

The political management (and mismanagement) of climate change may thus mirror all our successes and failures in other realms of human activity. Even if the scientific uncovering of man's impact on weather and climate had consisted mainly of positive possibilities, we would have seen a host of disputes and arguments about how such improvements were to be distributed; whenever the enhancement of the physical sciences converts "an act of God" into "an act of man," political tensions arise. But the sad news is that we may now see such disputes emerge against a background of a globally worsening environmental situation.

ANTARCTIC RESEARCH: IMPORTANCE FOR GLOBAL CHANGE

by

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INTRODUCTION

General circulation climate-modeling calculations suggest the Antarctic continent may serve as an early warning system for future global changes. Model results show increases in greenhouse gases will cause climatic heating, which is magnified many times in the polar regions (1). Global surface temperature measurements show a rise of 0.08 C per decade since 1958, but, in the polar regions only, there was a slight decrease in measured temperatures from 1973 to 1987 (2). For these reasons the Antarctic climate has become an especially important focus of scientific efforts.

Antarctica constitutes 10% of the land area of the globe (3) (which is about 1.5 times the size of the United States), is the coldest continent on earth, and is surrounded by three oceans. Ninety-eight percent of Antarctica is permanently covered by ice and 90% of the world's ice is contained on the continent. Thus, this land-supported ice is especially significant for global change since decreases in its abundance would directly alter the sea level, causing inundation of coastal regions.

There are no peoples that are native to Antarctica and, with the signing of the Antarctic Treaty, it remains a vast expanse to be used for peaceful purposes only, with complete freedom for scientific investigation (4). Territorial claims are held by Argentina, Australia, Chile, France, New Zealand, and the United Kingdom. There were 12 countries (with 60 research settlements, see Figure 1) that signed the original Antarctic Treaty and, since 1961, it has remained as a commonly-held heritage for all people. Because of the forces of global change, this common heritage may be altered significantly. This gives an additional incentive for consideration of the region.

UNIQUENESS OF THE ANTARCTIC CONTINENT

A cross-sectional view of the Antarctic continent (see Figure 2) displays a central region of high altitude. The thickness of the permanent ice sheet averages more than one and one-half kilometers in thickness and in places is almost 3 km thick. Surrounding this central region are huge ice shelves, the Ronne Ice Shelf in the Weddell Sea and the Ross Ice Shelf in the Ross Sea.

In the global balance of energy, Antarctica serves as a heat sink. The exchange of heat as latent energy produces temporal variations in the Antarctic energy balance through changes in the continent's ice extent and surface albedo. A less reflecting surface than ice absorbs more incoming solar radiation, increasing the surface heating. In contrast, during the austral (Southern Hemisphere) winter, sea-ice more than doubles the extent of the reflecting surface.

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Many processes contribute to the energy balance of Antarctica: solar and terrestrial radiation, sensible heat (heat derived from kinetic energy) exchange, evaporation, precipitation, melting or freezing, salt and mass flux in the oceans, transport of floating ice, and atmospheric and oceanic advection (see Figure 3). Changes in the extent of sea ice can alter the heat flow from the ocean to the atmosphere, which in turn effect the atmospheric circulation and the meteorological variables related to weather. Changes in the Antarctic as a heat sink can, in turn, cause changes in the atmospheric and oceanic flow in other regions of the globe.

EXAMPLES OF RECENT ANTARCTIC RESEARCH FINDINGS IMPORTANT TO GLOBAL CHANGE

In 1985 a team of scientists from the British Antarctic Survey announced their data showed an increasing stratospheric ozone hole (from 12 to 22 km), which occurred every spring since 1979 over Halley Bay. The American scientific community hurried to assemble a group to study the phenomenon the following spring. From their measurements, explanations relating to the solar cycles were ruled out, leaving the team leader, Susan Solomon, to state that the only theory which had not been ruled out by their research was the destruction of ozone by free chlorine (5).

The following year a much larger group, representing four nations and 19 different organizations, conducted aircraft, balloon and ground measurements. Satellite measurements were also available. The team found the geographic area of the ozone hole was twice as large as the area of the United States and the ozone concentrations were half the values measured prior to the appearance of the hole. In some regions no ozone was observed. Because the hole was as deep as possible, there was concern that it might next expand in area. In the following year, three of five Australian ozone-monitoring stations observed a sharp decrease in ozone in December. The decrease lasted for three weeks yielding the smallest ozone values for that month since ozone measurements began. Because of these findings, the Montreal Protocol was quickly developed, thereby limiting the future human emissions of the principal long-lived chlorine compounds.

Another example of recent Antarctic research is the Soviet scientists' 1987 ice-core studies at Vostok station. As part of the study, French scientists made measurements of composition of the air trapped in the ice cores (6). These measurements yielded information on the climate from the last 160 thousand years. The abundance of CO_2 in the cores was assumed to relate to the ambient level of CO_2 at the time the air was trapped, and measurements of the isotope ratios (O18 to O16) gave the corresponding ambient atmospheric temperature at the same time. Changes in CO_2 were shown to explain 90% of the temperature variance at Vostok. These conclusions lead to the idea of weak forcing of climate due to changes in the orbit of the earth, with strong amplification by induced changes in atmospheric CO_2.

These are but two examples of the important and extensive research recently conducted in the Antarctic area (7).

EXAMPLES OF FUTURE RESEARCH OF IMPORTANCE

In addition to the work mentioned previously, many other fields of science relating to environmental change need to be studied in the Antarctic (4).

Quantitative measurements of the heat budget can be correlated with the meridinal transfer and mixing of heat between the atmosphere and oceans. The southern ocean is especially significant since this area is crucial to ocean ventilation because it supplies cold, low-salinity water. The exchange of heat and fresh water drives the thermohaline circulation (i.e., the large-scale oceanic circulation driven by the combined effects of the temperature and salinity) while the sea-ice moderates it. In fact, the Antarctic Circumpolar Current is the only known global-scale current. The World Ocean Circulation Experiment, a current international study of ocean dynamics, will help to extend our understanding and modeling capabilities for the world's oceans. In addition, a study of the heat, momentum, fresh water transport, and the interaction between different scales of interaction (differently sized eddies) offers enormous possibilities for understanding the global thermal balance. Studies of trace constituents in the surrounding oceans can also help to understand the biogeochemical balance of the greenhouse gases.

Antarctica also holds great promise for the study of glaciology, plate tectonics, and a detailed history of the response of the ice sheets as they relate to changes in environmental forcing factors. It is especially urgent for the study of glacial surges and their causes, as well as iceberg calfing. (Note: an iceberg twice the size of Rhode Island was recently reported (8) having broken off from the Ross Ice Shelf along the Bay of Whales (see Figure 2). This single iceberg represented 2-3 times the amount of ice that normally breaks off in a given year.)

For the biologist, Antarctica holds great research potential to determine the evolution of the earth's biosphere with climate change, its role in the development of biotic bridges, and their impact on paleobiology (biology which explains life at a much earlier time). One biological area of particular significance involves the study of marine biological communities and their relationship to the ice-edge zone. Antarctic terrestrial ecosystems contain very few species, but these species have adapted to the continent's extreme environmental conditions of cold, drought, and extended periods of light and dark. Physical or chemical mechanisms of enzyme catalysis and gene cloning at low temperatures are especially important for the study of the mechanisms controlling biological processes and gene action (9). Investigations of sea-ice biota are also promising.

AREAS OF CONCERN RELATIVE TO THE ANTARCTIC

Despite the great success of the Antarctic Treaty and the devotion of scientists to peaceful investigation, many issues remain unsettled relative to this continent:

1. There is no Treaty Secretariat to house and exchange valuable scientific information.
2. There is no mechanism to encourage the participation of nonvoting Treaty members.
3. There is overcrowding of scientific camps in certain areas (10).
4. Pollution, solid waste disposal, and ocean dumping by support ships and tourist vessels remain critical problems of concern (11).

Areas of future concern include:

1. The impact of a rising tourist industry may severely stress the ecosystem of the Antarctic. (12).
2. Overfishing of the waters surrounding Antarctica may threaten the entire ecosystem as well as limit the potential for the fishing industry (13).

3. Demands for commercial exploitation of the continent's mineral resources may become substantial with no good mechanism for limiting the environmental consequences (14).
4. Drilling for oil would expose the continent to the possibility of an oil-well blowout at a time when winter conditions would prohibit capping it for months (15). There is also an enhanced chance for a blowout in this region since icebergs extend far underwater, destroying anything in their way, including piping.

Maintaining the ecological balance of this vast area is exceedingly important. Krill constitute the base for the entire trophic (requiring the same type of nutrition) food chain so they support an estimated 33 million seals, 500,000 whales and 60 million seabirds that inhabit this area (16). The phyto- and microplankton (types of minute plant life that live in the ocean) production is estimated to be between 260-6400 million tons annually (17), which is also important for maintaining the CO_2 balance since they use a portion of the oceanic CO_2 taken up from the atmosphere.

In addition to the above, the future handling of search and rescue missions and the legal responsibility of the parties involved will continue to offer many vexing problems.

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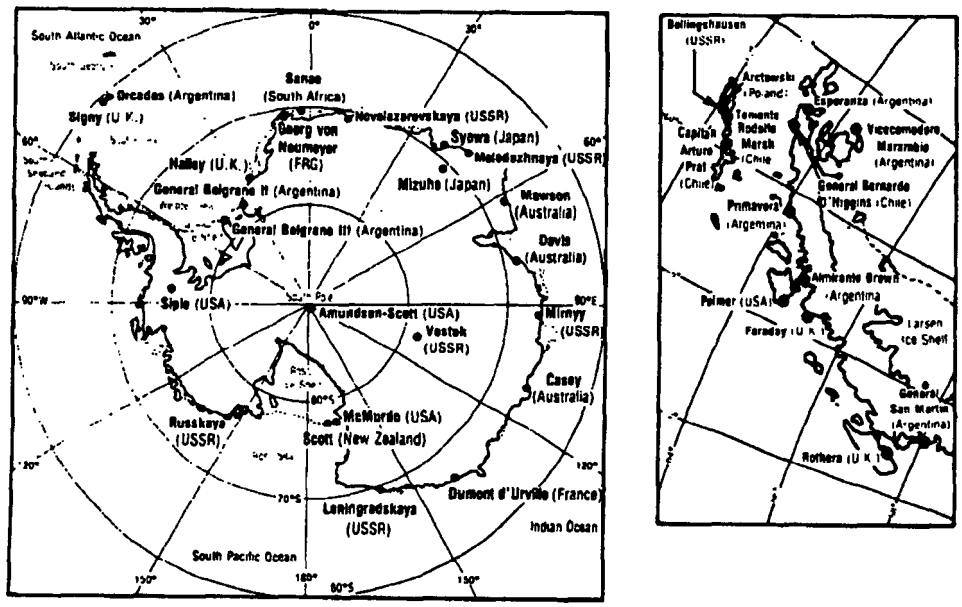


Figure 1. Locations of research settlements on the Antarctic Continent (18).

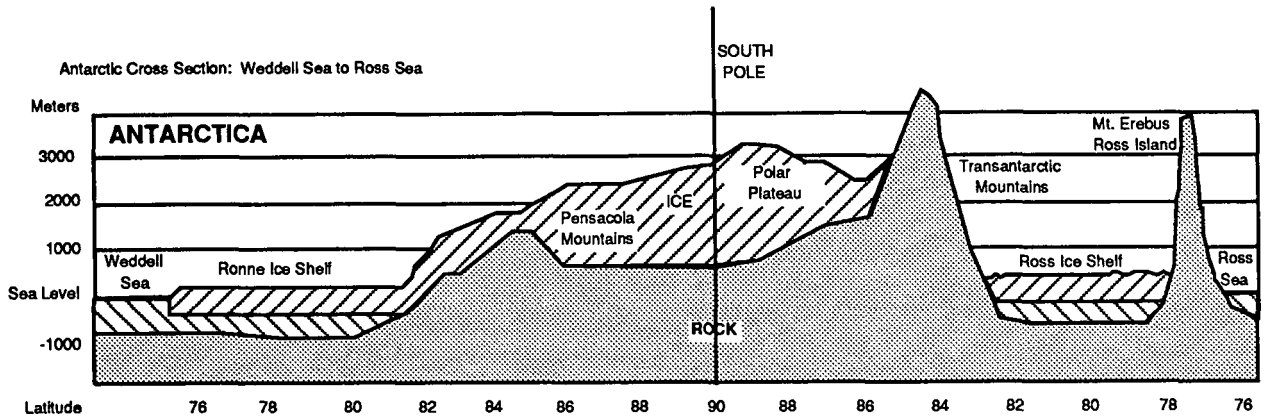


Figure 2. Cross-sectional view of the Antarctic region (16).

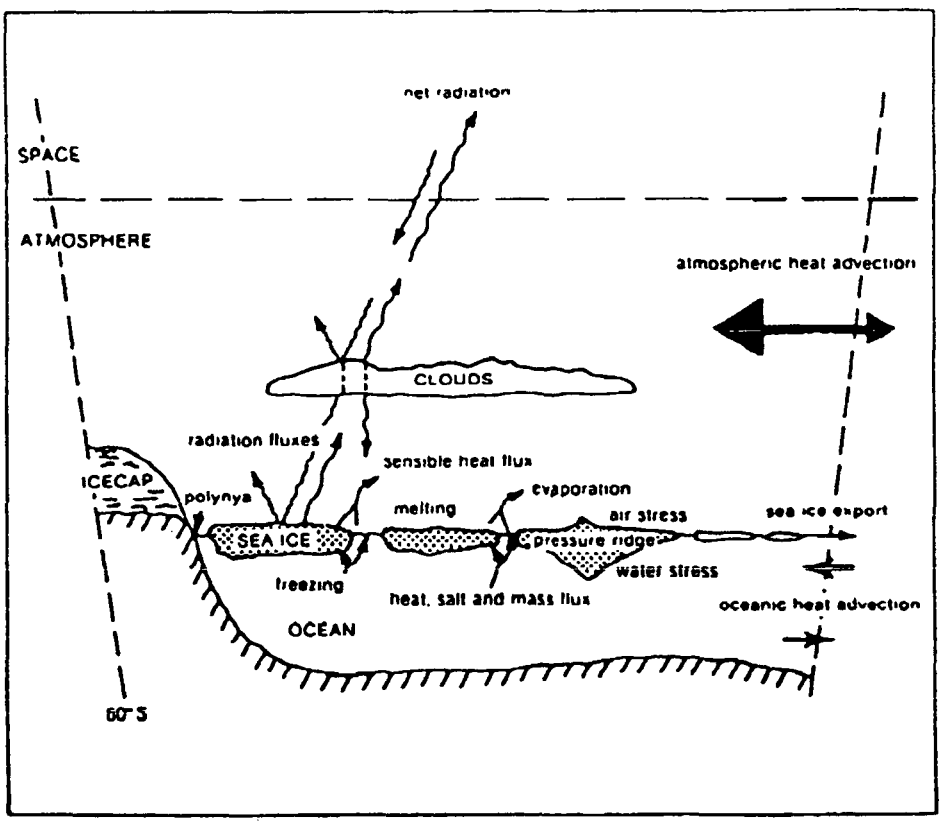


Figure 3. Processes that control the energy balance of the ice-air-sea interactions in the Antarctic region (18).

UNDERSTANDING GLOBAL CHANGE: THE INTERNATIONAL GEOSPHERE-BIOSPHERE PROGRAM

by

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INTRODUCTION

Since the beginning of human life on earth, our species has struggled with a widely diverse and ever-changing environment. These changes are the result of massive forces that continue to change the environment of the earth even to this day. Along with these large and often slow natural changes, human development has created rapid changes of the earth's surface, mainly so that modern society can survive, develop, and prosper. An analysis of the earth's surface from a satellite-view perspective shows large metropolitan settlements with extensive energy usage (light spots in the night sky), huge industrial complexes, gigantic water control systems, coast-to-coast highway infrastructures, and significant decreases in the number of biological species, their location, and range. Not only has our global surface changed, but many other factors that contribute to a global balance, including such important contributions as the trace greenhouse-gas constituents of the atmosphere and the abundance and distribution of ground water. It is only in recent times, when our populations have become so large, so prosperous, and so advanced, that significant human-caused changes have become possible or necessary.

It is also a rapidly changing time in history for the evolution of the environmental sciences. The capabilities of satellites, global communication, and megacomputers can be combined to rapidly yield access to enormous information banks, which relate many overlapping areas of knowledge about the globe. Without modern electronics and remote sensing, these information banks would take hundreds of man-years to develop, thereby making the acquired knowledge relatively worthless for rapid prediction capabilities. It is through modern technology that it becomes possible for scientists to undertake global-scale studies to document the full changes of the earth and to attempt to sort out the relative contributions of human activities. This human factor has become increasingly more important in order that assessments can be made of the future availability of both renewable and non-renewable resources, in particular as they affect sustained development.

INITIATION OF THE INTERNATIONAL GEOSPHERE-BIOSPHERE PROGRAMME(1)

With these concepts in mind and while feeling a responsibility for human stewardship of the earth for both the present and future generations, the International Council of Scientific Unions, at its General Assembly in Berne in 1986, undertook to establish the International Geosphere-Biosphere Programme, a Study of Global Change. Since then this programme has become known internationally as the IGBP.

The objectives of the IGBP undertaking are:

- to document and predict global change,
- to observe and improve understanding of the dominant forces,

- to understand the interacting phenomena in the total earth system, and
- to assess the effects of global change that will cause large-scale and important modifications in the availability of renewable and non-renewable resources.

For the IGBP to identify and separate the role of natural versus anthropogenic changes, it was decided to study past climate changes and the resulting effects. If models could be developed that would adequately predict the past changes, together with the impact of changes in the biogeophysical cycles, the anthropogenic factors could be included later as source terms which would give a reasonable and reliable physical basis for a predictive model. It would, of course, be important to identify and include all the principal factors causing climate change and the many nonlinear interactions among the different components of the global system. The final goal would be to identify specific areas where change would be expected to be the most rapid and also to predict the effects of climate change on a regional scale.

ORGANIZATION OF THE IGBP

To undertake this study, four Coordinating Panels were identified:

- Terrestrial Biosphere-Atmospheric Chemistry Interactions,
- Marine Biosphere-Atmosphere Interactions,
- Biospheric Aspects of the Hydrological Cycle, and
- Effects of Climate Change on Terrestrial Ecosystems.

Quantitative knowledge of these component interactions (see Fig. 1) is very incomplete, and the sensitive balance between natural and anthropogenic effects can only be deciphered through a detailed resolution of the factors that control their magnitude, for example, the atmospheric chemistry of the greenhouse gases and their fluxes to and from each reservoir. A study of each of these interactions would help to assess the role of each component so that the physical basis for predictive models can be firmly established. Of particular importance is the role of tropical deforestation and the uptake of CO_2 by the marine biosphere in the ocean.

Four IGBP Working Groups were also established to assess the current and anticipated research capabilities in:

- Global Geosphere-Biosphere Modeling,
- Data and Information Systems,
- Techniques for Extracting Environmental Data of the Past, and
- Geosphere-Biosphere Observatories.

The connections between the component interactions can only be better understood through more sophisticated global geosphere-biosphere modeling. The full general circulation of the atmosphere must be considered along with radiation transfer, atmospheric chemistry, oceanic circulation, and terrestrial and marine biological processes. Paramount in this development will be the air-sea interaction involving both momentum transfer and material flux.

At the center of this major global study is the acquisition and handling of large data sets. Among the major quantities to be measured are the solar flux at a number of altitudes, cloud features and their relationship to the radiation balance, reactive species involved in tropospheric chemistry, the extent of the terrestrial biosphere and its interaction with the hydrologic cycle, land surface properties, ocean properties,

sea level, and ice and snow extent. Clearly, for an international undertaking of this size, it is imperative that many international organizations be involved in the measurement, coordination, standardization, validation, and data management. At a recent meeting (2) sponsored by the Smithsonian Institution in Washington, it was stated that the data load expected amounts to 10 000 high-density computer tapes of data per day. Obviously top priority must be given to the techniques for data reduction and extraction of environmental information.

Geosphere-biosphere observatories are the only means for full development of our understanding of interactions within various ecosystem types. The goal is to identify and decode different scales of changes (that is, global versus regional or local), to help integrate all the various disciplines and to serve as a means for documenting and verifying predictive models.

IMPLEMENTATION OF THE IGBP

For implementation of the IGBP, Special Committees are now being formed representing each participating country. Currently 46 countries have formed Special Committees. It is expected that these Committees will serve as the core of the activities of the IGBP. For the implementation of the program, each participating country is asked to support the IGBP by an amount totaling $1 200 000 US dollars over nine years. This money is for the maintenance of the infrastructure of the IGBP. Clearly the research projects comprising the IGBP will need to be financed by individual countries and because of the vast extent of the resources needed, no attempt has been made to estimate the costs of the program. The measurement program is expected to extend over a decade.

As mentioned earlier many international organizations relate directly to the activities and interests of the IGBP. To coordinate the IGBP with the activities of these organizations it will be necessary to establish cooperative agreements.

The ICSU is currently contacting industrial organizations to ask for their guidance and help for the IGBP in whatever way possible. Only by the concentrated efforts and support of all interested groups will the success of this ambitious undertaking be assured.

Additional information about the IGBP may be obtained from the US Committee (3) or from the Secretariat housed at the Swedish Academy of Sciences in Stockholm (4).

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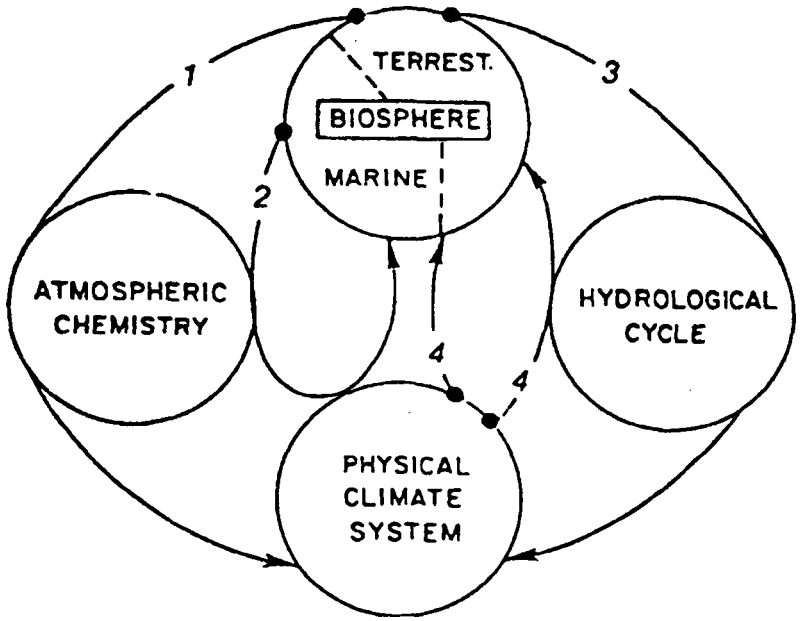


Figure 1. Relationship of the Coordinating panels to the earth system. (1) The coupling of the terrestrial ecosystems and atmospheric chemistry and its linkage to the global system; (2) the relationship between the ocean productivity as well as the role of nutrients and trace elements as they relate to the global system; (3) relationship of the dynamic coupling between the land-atmosphere interface and its impact on climate; and (4) relationship of vegetation and soil to natural ecosystems and the global climate. Adapted from Reference 1.

ENERGY-TECHNOLOGY R&D: WHAT COULD MAKE A DIFFERENCE?

by

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SUMMARY

Two major uncertainties cloud the future energy system: the level of energy demand and the consequences of the greenhouse effect. Energy-technology R&D provides technological alternatives for the future energy system. The Oak Ridge National Laboratory (ORNL) recently completed a broad survey of energy-technology R&D.[1] The survey revealed a rich variety of options for both end-use technologies and energy supply technologies. However, none of the nonfossil energy sources are ready to substitute for fossil fuels at the scale necessary to mitigate the potential consequences of the greenhouse effect.

INTRODUCTION

Energy-system R&D has three objectives: to solve current problems, to provide attractive technological alternatives for the wide variety of possible future circumstances, and to provide new technological opportunities. The principal problems of the energy system are:

1. Impacts of the energy system on the environment, human health, and safety. Concern about these impacts is growing in both industrialized and developing nations. Some of the primary energy-related environment, health, and safety issues are: the greenhouse effect, stratospheric ozone depletion, acid rain, hazardous waste, and smog.
2. Energy insecurity and price instability. As oil prices have dropped, consumption has started to increase again, and oil imports have moved sharply upward, perhaps setting the stage for future price shocks.
3. Energy needs of less-developed countries. Improving the economic condition of less-developed countries is morally important and vital to world stability. Reasonably priced energy will be essential to improvement. The rapidly growing demand for primary energy sources by developing nations will put additional stress on the environment.
4. Problems with nuclear power. Although nuclear power generated 20% of U.S. electricity in 1988, its future is uncertain. Problems include high costs, reactor safety, waste management, negative public opinion, and nuclear proliferation.

Two major uncertainties about the future complicate the selection of an energy-technology R&D agenda. The first is the growth of demand for energy. Sustained economic growth is a societal goal. As the world economy grows, the demand for energy services will tend to increase. The experience of the past 15 years has shown that economic growth can occur without increase in the demand for primary energy sources. What will happen in the future? The future level of consumption of energy is uncertain. The second

uncertainty is environmental. The nations of the world could become sufficiently concerned about the potential consequences of climate change to restrict the burning of fossil fuels.

Energy-system R&D should provide attractive technological alternatives for future circumstances. However, future circumstances are uncertain. To evaluate R&D opportunities, the ORNL study defined three future circumstances that illustrate the range of possible futures.

Circumstance 1 (high efficiency, zero energy growth). A basic principle of economics is that there is no free lunch. However, technological progress can provide a low-cost lunch. In Circumstance 1, technological progress (both in hardware and in social institutions) provides economic growth for the world without a corresponding growth in energy consumption. The increase in efficiency occurs without coercion (no taxes or standards) through the natural operation of free market economies. As is the case for any free lunch, this circumstance is highly desirable. A zero-energy-growth future greatly reduces the pressure on limited resources of oil and gas and on the environment.

Circumstance 2 (energy growth). Circumstance 2 results if there is no free lunch and Circumstance 1 does not occur. In this circumstance, primary energy demand grows substantially faster than in Circumstance 1, but slower than the growth in the economy. Possible reasons for Circumstance 2 are limited improvements in the technology, low-cost energy sources, or market imperfections and institutional barriers that impede the adoption of efficient technology.

Circumstance 3 (environmental concerns curtail fossil sources). In Circumstance 3, the consequences of the greenhouse effect are considered to be so severe that the use of fossil fuels must be curtailed. This circumstance would lead to the most profound change in the energy system. The nations of the world would adopt policies to encourage nonfossil sources, biomass (for transportation fuels), nuclear power, and solar energy and to encourage efficiency.

In the next section, we will define the elements of a balanced-energy-technology R&D strategy and identify promising R&D options. Section 3 presents our conclusions.

PROMISING R&D OPTIONS

Based on our review of current problems with the energy system and of possible future circumstances, a balanced-energy-technology R&D strategy should have the following objectives:

- improving the efficiency and flexibility (fuel-switching capacity) of energy use and conversion technologies;
- improving fossil-fuel supply technologies by reducing environmental, health, and safety impacts and by extending and improving the availability and flexibility of indigenous resources;
- developing and improving nonfossil supply technologies; and
- developing relevant areas of science and crosscutting technology.

What are the promising opportunities for R&D in each of the four areas? To address this question, the management of the Oak Ridge National Laboratory (ORNL) organized a study. More than 100 ORNL staff members (and a few colleagues from other laboratories) were organized into teams to review the status of technology in 19 areas covering end-use efficiency, fossil and nonfossil supply, and crosscutting science. Each team prepared a report that identified significant cost-effective technological advances that could be made within the next 50 years.

A synthesis team was chosen to coordinate the study. The synthesis team developed a matrix methodology to evaluate R&D options. Sixteen criteria in six categories were applied. The criteria emphasize the magnitude of the potential energy contribution of the technology (assuming successful development and implementation), the economic advantage that may accrue, the effect on national energy security, and the environmental, social, and international impacts. The 50 most promising R&D options are listed in Table 1 (a discussion of the status of the 50 options is provided in reference 1).

End-Use Efficiency

Imperfect consumer information, the tendency to invest for lowest first cost rather than for lowest life-cycle cost, uncertain energy prices, and uncertainties about the reliability and performance of new technologies are barriers to the penetration of more efficient technologies. A better understanding of these barriers and of the effectiveness and costs of government and utility actions to reduce them is needed.

Fossil Energy

Fossil fuels, particularly oil and gas, are marvelous energy sources because they are easy to use at nearly any scale and they are portable and transportable. At present use rates, world conventional oil resources should last 60 years and gas 130 years, and unconventional sources are at least as large. Coal resources are many times greater. Thus, fossil fuels are very tough competitors, and only environmental considerations such as CO_2 or a major cost breakthrough by nonfossil technologies will cause the world to move from its reliance on fossil fuels in the next half century. Since fossil fuels will be used for many years, domestic sources should be improved. R&D should develop technologies that can use coal more cleanly and efficiently (or convert it to liquids or gas) and that extend oil and gas resources.

Energy technology R&D options of greatest promise:

Transportation:	Advanced engine technologies Continuously variable transmission Improved aircraft efficiency Automated dynamic traffic control
Buildings:	Heat pumps Lighting Smart control systems Envelopes Manufactured components and buildings Computer-asisted design Existing building retrofits

Industrial:	Catalysts Sensors and controls Separations Advanced heat management Cogeneration Pulp and paper processes Steel processes Agricultural techniques
Electricity:	Superconductivity applications Power electronics
Advanced Conversion:	Aeroderived gas turbines Brayton cycle Kalina cycle Fuel cells Hot-gas cleanup
Storage:	Advanced batteries Thermal storage
Petroleum:	Enhanced oil recovery Field characterization techniques
Natural Gas:	Exploration and drilling techniques Unconventional gas techniques
Coal:	Oil substitutes Fluidized-bed combustion Bioprocessing Gasification Liquefaction
Nuclear Power:	Improving existing LWR technology Modular high-temperature gas reactor Liquid-metal fast-breeder reactor Waste management techniques

Fusion:	Reactor systems Fissile-fuel breeder
Biomass	Feedstock development Conversion technology Municipal solid-waste processing
Solar Electric:	Photovoltaic energy conversion Solar thermal Hydroelectric Wind turbines

Nonfossil Energy

Nuclear power is the most likely near-term nonfossil source that can be deployed at large scale and at costs competitive with coal. Although nuclear power already supplies one-fifth of U.S. electricity, it faces significant constraints on expansion to the much larger scale that would be needed to control the greenhouse effect. R&D to improve the performance of existing light-water reactor technology, to develop advanced reactors with passive safety features, and to provide the means for better management of wastes may be necessary for public acceptance of such large-scale deployment. Large-scale use will increase public concerns about the proliferation of nuclear weapons.

Biomass (woody and herbaceous plants) can be a significant source of liquids for transportation (10 to 15 quads per year of liquid fuels). Photovoltaics, solar thermal electric, and wind have been improved enormously but are still expensive. Fusion-energy R&D is making significant progress but a prototype power plant is still decades away.

Crosscutting Technology

Much of our optimism about the potential for better energy technologies derives from the promise of crosscutting science and technologies. Revolutionary developments in materials science, in computing and microelectronics, and in biotechnology seem certain to make profound changes in the ways we transform, transport, and use energy. The possibilities range from high-temperature superconducting devices, such as long-distance power transmission lines, to bioengineered plants for liquid fuels, to smart controls for energy services in our homes and industries.

CONCLUSIONS

The Oak Ridge National Laboratory (ORNL) recently completed a broad survey of energy-technology R&D. The survey revealed a rich variety of options for both end-use technologies and energy-supply technologies. However, current technology is not ready to substitute for fossil fuels at the scale necessary

to mitigate the consequences of the greenhouse effect. A three-prong strategy is required: improve the efficiency of energy conversion, improve nonfossil energy sources, and improve technologies tailored to the needs of developing nations.

The technical potential for cost-effective improvements in the efficiency of energy use is very large and growing. Examples include: advanced automobile engine technologies, heat pumps, smart control systems, and aeroderivative gas turbines. The buildings sector is decentralized and the market penetration of more efficient technologies is slow. Improved public and private institutions are required to overcome the barriers to cost-effective technologies.

Although none of the nonfossil sources are both competitive with fossil fuels and deployable at a scale sufficient to reduce CO_2 emissions, the prospects appear bright for producing much improved nonfossil sources, including: passively safe nuclear power, biomass liquids for transportation, photovoltaics, solar thermal electric, wind, and fusion. Although hydroelectric power is a limited resource, many opportunities exist in the United States and the world for cost-effective increases in installed capacity.

In the decade from 1977 to 1987, CO_2 emissions in the OECD countries were constant, emissions by the industrial centrally planned economies increased at 2% per year, and emissions from the rest of the world (the developing economies of Latin America, Africa, and Asia) increased at 4% per year. If these trends continue, the developing countries will dominate future emissions of CO_2. The developed countries should improve technologies that allow economic growth without increased consumption of fossil fuel. Examples include: improved efficiency in transportation and buildings, cogeneration, advanced conversion, biomass, and solar electric.

The combined energy-technology budgets for the Department of Energy, the Nuclear Regulatory Commission, the Gas Research Institute, and the Electric Power Research Institute amounted to about $2.8 billion for 1988. We made the following estimates of the additional R&D expenditures needed to develop the technologies needed to reduce CO_2 emissions.

1. Improve the efficiency and economics of end-use and conversion technologies. This area of R&D should not be budget limited so long as important options are yet to be explored. Our study has identified many promising R&D options to improve efficiency. We would propose a several-percent-per-year, phased increase to twice the current level. An important part of the effort would be to evaluate and experiment with policy options that could stimulate the adoption of improved, more efficient technologies. Additional cost is about $300 million/year.
2. Improve nuclear power. This area of R&D requires technology demonstration; commercial-scale technologies should be built and thoroughly tested under field conditions. In the next 10 years, two reactor concepts should be demonstrated: an advanced light-water reactor and the modular high-temperature gas-cooled reactor. Demonstration of the liquid-metal fast-breeder reactor with passive safety features could be deferred until the first decade of the next century. Additional cost might be $3000 to $4000 million over the next 10 years, or $350 million/year.
3. Solar and other renewables. The budgets for biomass, hydroelectric, photovoltaics, solar thermal electric, and wind should be increased by a factor of two over several years. Additional cost is about $200 million/year.
4. Fusion. About $1 to 2 billion/year is currently expended worldwide on fusion power research. If this were well coordinated, it should be sufficient to establish technical and economic feasibility in 15 to 20 years.

5. Technologies for developing countries. Currently, the U.S. Agency for International Development spends about $200 million/year on energy problems in less-developed countries. If new technologies are to be developed and demonstrated adequately, a much larger effort is required. We estimate that the total U.S. effort needs to be in the range of $300 to $400 million/year. Again, the total effort needs to be shared with other industrialized nations. The additional annual cost is about $150 million.

Thus, our estimate of the added R&D budget required to prepare technologies to reduce CO_2 emissions would average about $1.0 billion/year over the next 10 years. This represents a one-third increase of the energy technology R&D expenditures by the nation for 1988. In this era of budget deficits, a major increase in expenditures will require a substantial national commitment.

ACKNOWLEDGMENTS

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INTERNATIONAL SCIENTIFIC COOPERATION IN THE ARCTIC

by

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SUMMARY

Cooperative scientific research in the Arctic plays a particularly important role in confidence building among the nations of the circumpolar north—which include the two superpowers. The Arctic is a very special region from many points of view: 1. it is a most sensitive "early warning system" for global climate change; 2. it is in itself an important participant in the control of global change through its active links to the world oceans and the total atmosphere; 3. it is one of the least understood components of our planet; and 4. it is a most important region from an economic and strategic point of view. There is a great demand for scientific research, which by necessity must be international—yet international cooperation in the Arctic is most difficult. This article describes these difficulties and discusses newly emerging opportunities in the light of recent positive international developments.

INTRODUCTION

Economic and social development of all nations is becoming increasingly dependent on the advances in technology, which in turn depend on the unpredictable results of science. Scientific research is becoming complex and expensive, requiring sophisticated instruments, extensive logistic support bases, and huge computer centers and laboratory installations. Environmental research focuses on the integral Earth, global environment, global ecological and human population trends, and global change—endeavors that no single nation, let alone individual research groups, can undertake on their own.

Many measurements must be made simultaneously at different locations and in such a way that they can be fed into a common data base available to all participating scientists. This requires international cooperation, in which agreements are reached on what to measure, when and where; on instruments and measurement standards to be used; on data formats; sometimes even on how the data are to be analyzed.

Science transcends cultural, ideological, and nationalistic narrowness. Programs of international scientific cooperation have given participating scientists the possibility of seeking common denominators that encourage cooperation despite political or ideological differences; and they have made it possible for scientists to voice and publish ideas about international affairs, even when these ideas were at variance with official government positions.

International scientific cooperation has thus prepared the way for international cooperation in other areas. For instance, scientific programs have served on several occasions as preludes to diplomatic discussions, and they have led to international treaties such as the Antarctic Treaty of 1961, the Nuclear Atmospheric Test Ban Treaty of 1963, the Space Treaty of 1967, and the Montreal Protocols on Chlorofluorocarbons of 1987. The discussions in scientific fora of the effects of "nuclear winter" have had a tremendous impact on political and strategic thinking in the superpowers.

Cooperative scientific research can be an important element in confidence building measures among countries, East-West and North-South. This is particularly true in current times, in which we are witnessing

a transition from national/military security concerns to global/environmental security concerns. Cooperative research in the Arctic plays a particularly important role in confidence-building among the nations of the circumpolar north—which include the two superpowers.

Usually, "the Arctic" is defined in geographic terms—for instance, as the region north of the Arctic Circle or the region bounded by the 10° C July isotherm. For the purpose of this article, however, it is more appropriate to define the concept in a broader, operational way. We shall use the term "Arctic" to designate those northern high-latitude regions in which the effects of cold climate, a large-amplitude photocycle, short and intensive growing seasons, sea ice, scarcity of fast surface transportation routes, and geomagnetic and auroral perturbations, individually or in concert, prevent a straightforward transplantation of "traditional" technologies and lifestyles developed at lower latitudes.

The importance of international scientific cooperation in the polar regions has long been recognized; indeed, the First Polar Year of 1882/83 was historically the first major, multidisciplinary international scientific enterprise ever to be carried out. It was followed by the Second Polar Year fifty years later. Their successor was the International Geophysical Year (IGY) of 1957/58, with a strong arctic research component; the IGY launched both the space age and the international antarctic research program.

Antarctic research cooperation is sometimes pointed out as an ideal to be emulated for the Arctic. However, the differences are profound. First, although there exists an international treaty on Antarctica, the Arctic is one notable area as yet largely untouched by formal international agreements (the Spitsbergen Treaty of 1920 is geographically constrained). Secondly, in contrast to the Arctic, there are no indigenous people in Antarctica, there is as yet no nonrenewable resource development there, and military activities are banned and territorial claims suspended as long as the Antarctic Treaty remains in force. Thirdly, although antarctic research is mainly driven by scientific curiosity, much of arctic research is directed toward solving practical problems related to the inevitable northward expansion of human activity and to national defense.

Indeed, many research needs in the Arctic are directly linked to economic, military, and political interests. This makes international cooperation in research difficult; in certain geographic regions and in certain fields of research, international cooperation becomes practically impossible when expected research findings are classified as sensitive or proprietary by governments or industrial firms, respectively, or when research activities have the potential of yielding significant intelligence data. Even within a single country certain arctic research issues are socially or politically sensitive.

The purpose of this article is to discuss some of the inherent difficulties that international scientific cooperation in the Arctic has to face and to describe the new opportunities that are emerging in the light of recent developments in the international arena (Roederer, 1988).

INHERENT DIFFICULTIES

The principal factors that present a challenge to the development of international cooperative research projects in the Arctic are related to the strategic and economic importance of the region.

Outer Space and Airspace over the Arctic

The shortest distance between Asia, Europe, and North America, is over the Arctic Ocean. The orbital flight paths of intercontinental ballistic missiles traverse the space over the northern polar cap. For this reason, land-based surveillance and early-warning systems are emplaced in the Arctic, and much of the

action in a strategic defense system (SDI) would have to take place in near-earth space above the arctic atmosphere.

The common boundary between the two superpowers lies in the Arctic (in the Chukchi Sea, Bering Strait, and Bering Sea). Since the Soviet Union does not have adequate forward bases overseas, the Arctic is a natural route for its strategic bombers. Although the United States does have the option of overseas forward bases, these lie on foreign territories and are vulnerable; the polar route is considered crucial, especially for the later stage of a retaliatory strike.

The Arctic Ocean

The Soviet Navy must cope with severe geographic restrictions: its Baltic, Black Sea, and Pacific fleets depend on passing through foreign-controlled straights or narrow areas to reach the high seas. The passage between Norway and Svalbard being the exception gives particular strategic importance to the Soviet Northern Fleet for the deployment of short-range missile submarines off the US East Coast. In view of this threat, the US set up an elaborate system to intercept Soviet submarines in transit through the Greenland-Iceland-UK gap. The Soviet Union responded in the early seventies with the deployment of Delta-class (later also Typhoon-class) submarines equipped with long-range missiles, capable of striking targets in North America, Europe, and China with a launch from arctic waters. This development converted the Arctic Ocean from a "military flank" during the 1950-70 period to a "military front" in the 1980's (Ostreng, 1988).

Natural Resources

There is no need to emphasize the importance of resource development in the Arctic. In the United States, 11% of the total petroleum usage is derived from Alaskan North Slope crude (this represents over 20% of the domestic oil production); the Bering Sea fish catch comprises 25% of the total US commercial catch. The oil reserves in the US Arctic National Wildlife Refuge alone are estimated at 3.23 billion barrels, and the coal reserves north of the Arctic Circle may exceed the total reserves of the entire lower 48 states. Deposits of strategic minerals in the US Arctic are suspected to be abundant but have not yet been quantitatively appraised.

In the Soviet Union, in addition to oil and gas extraction and the fisheries industry, a vast effort of general industrial and urban development of the Arctic is in progress, aided by marine transportation routes along the northern shores of Siberia that are kept open by a formidable fleet of icebreakers up to six months each year. Today, arctic resource exploitation plays a fundamental role for the integral economic growth of the Soviet Union.

The harvest of marine resources in the Bering Sea and subarctic waters by Japan, Taiwan, and Korea plays an important role in their national diets and overall economies. On an international scale, the Bering Sea provides almost one-tenth of the world's supply of fishery products.

Transboundary Transport of Atmospheric Pollution

The Arctic has a vulnerable environment, highly sensitive to perturbations from outside. The delicate balance between its physical, chemical, and ecological components, governed by the very low rate of biogenesis and chemical turnover, makes the Arctic an "early warning system" for global change. This

includes its sensitivity to atmospheric and water pollution. Industrial effluents and aerosols from lower latitudes in Europe and North America appear in the form of "arctic haze" over large regions of the Arctic (Stonehouse, 1986). The absolute concentrations of pollutants are comparatively small and may not pose immediate health hazards to arctic residents. However, their long-term accumulation in lichens and subsequent release to subsistence wildlife and livestock feeding on them, as well as the magnitude of their effects on the radiation balance and the chemistry of the atmosphere, are still difficult to appraise, making this an important field of arctic research. And the behavior and trends of stratospheric ozone in the Arctic are only now beginning to be studied systematically. As scientific results are obtained, the sources of the pollution will be identified, and legal issues involving "fingerprinting" of the polluted air masses, industrial emission controls, and related international conventions will have to be addressed (Rey, 1986).

Social Issues

Aboriginal people have lived in the Arctic for millenia; honed by a harsh environment, they are trustees of a rich culture rooted in a subsistence lifestyle. They have achieved permanent residence only by living in perfect harmony with their fragile environment: they are an integral part of the Arctic ecosystem. Arctic natives now feel threatened. Their concern is about the long-term future: many of them believe that the current influx of western civilization is a passing event, a blip in their history of thousands of years of life in the Arctic. After all western amenities are gone, will their subsistence culture have survived? Will the subsistence prey have survived?

There is an increasing trend in the Arctic countries to strengthen the cultures and protect the lifestyles of indigenous populations subject to an expanding wave of industrialization and urbanization from the south. In several countries, including the United States, this aim has been made part of a national policy for the Arctic. On the other hand, and almost paradoxically, these policies also seek to enhance the economic benefits that development can bring to the native residents. As a result, many problems of the Arctic turn out to be more political and domestic than economic and international (Griffiths and Young, 1988).

Other Factors

There are other issues that may affect the planning and implementation of international scientific cooperation in the Arctic. Some of these factors are purely political, others purely scientific.

One political factor relates to the existence of disputes over marine jurisdictions. Between the US and the USSR there are questions about the precise demarcation in the Bering Sea (involving the Navarin oil basin); between the US and Canada there are questions about Canada's claim to arctic marine areas based on the sector principle (the region bounded by the meridians drawn from the eastern- and western-most points of a country to the North Pole), which the US does not recognize. Between Norway and the Soviet Union, there is no agreement on the extent of the coastal state jurisdiction offshore or on Norway's claim to exclusive jurisdiction over the Svalbard continental shelf.

In several countries, including the US, research in the Arctic must compete with research in Antarctica for funding. Although logistic costs of a given research operation are usually much higher for Antarctica than for the Arctic, in the US these costs are borne directly by the government agency responsible for antarctic research (the National Science Foundation), whereas the logistics costs for the Arctic must be budgeted explicitly in the individual research proposals. This puts US arctic research at a competitive disadvantage with respect to projects in Antarctica, at least in the US.

Finally, an overall complicating factor is that arctic science is eminently interdisciplinary, that arctic phenomena and processes cannot be studied in isolation, that these studies are very expensive, and that research planning is often dictated more by logistic considerations than by scientific rationale.

Constraints for International Research in the Arctic

All of the above puts great pressure on arctic research in the Arctic countries. Their industries and defense systems must be able to operate efficiently under arctic conditions. Their indigenous people in the Arctic must be protected from the detrimental effects of industrialization and the northward expansion of western culture, yet at the same time they should be afforded the benefits of such an expansion. Only scientific research—much of it requiring international scientific cooperation—can provide the necessary answers to the many related questions. This includes the need for reliable predictions of weather, ice conditions and ice motion, and space disturbances. However, because of strategic or economic considerations, there will always be a limit to how far governments will go in accepting pertinent arctic research subjects to be included in international cooperative projects (Ostreng, 1988).

There are important "boundary conditions" that will both influence the definition of domestic arctic research programs and constrain the organization of international cooperative programs during the foreseeable future. These boundary conditions have been summarized by Young (1988): "The Arctic will certainly remain a major theater of operations for strategic weapons systems during the foreseeable future. The impacts of nonrenewable resource extraction on arctic ecosystems and socio-economic systems will clearly require monitoring and regulation to control the industrial activities that give rise to arctic haze. The struggles of indigenous peoples to maintain the integrity of their cultures and achieve a measure of self-determination will continue in the face of militarization and the industrialization of the Arctic."

These factors unavoidably will keep the eight "Arctic countries" (Canada, Denmark/Greenland, Finland, Iceland, Norway, Sweden, US, and USSR) in a state of regional hegemony, and it would be rather unrealistic to expect that international cooperation in arctic research would soon become "open to all" in the same sense as most other international projects sponsored by nongovernmental scientific bodies are. This fact needs to be recognized, understood and accepted by the international scientific community. Active researchers seldom read what science policy specialists write: they just want to get their job done. Yet in the case of the Arctic, a lack of recognition and understanding of the true, complicated situation may lead the scientists into false expectations or to imprudence in the formulation of their proposals for international collaboration, which in turn would lead to disappointment when "government bureaucrats" turn them down on policy grounds.

NEW PROSPECTS FOR SCIENTIFIC COOPERATION IN THE ARCTIC

The question of establishing an international body to coordinate research activities in the Arctic is an old one. Proposals have been formulated on several occasions during the last three decades since the IGY, but they have never been implemented. Most cooperative ventures in arctic research have been conducted on an ad hoc basis. In terms of international nongovernmental organizations (NGO), there is no equivalent to the Scientific Committee on Antarctic Research (SCAR), established thirty years ago by the International Council of Scientific Unions (ICSU). The idea of a "SCAR of the North" has been advanced several times in recent years, but pertinent discussions never came to fruition. In particular, attempts to draw the Soviet Union into a multinational body of arctic research have systematically failed in the past.

Shortly after the establishment of the United States Arctic Research Commission in 1985, this author, then Vice Chairman of the Commission, stated at an international conference on arctic air pollution in Cambridge, England: "It follows from both the US Arctic Policy established by the President and the Arctic Research and Policy Act of 1984 passed by Congress, that the United States has a commitment to and responsibility for the promotion of international scientific cooperation in the Arctic. We sincerely hope that all Arctic nations will join in international research ventures. A better knowledge of the Arctic is not only necessary for scientific and technological reasons: it can contribute effectively towards an increased insurance for world peace" (Roederer, 1986).

In July 1986, Dr. James Zumberge, then Chairman of the US Arctic Research Commission, launched an initiative with informal discussions among scientists from arctic nations attending a SCAR meeting in San Diego, California. There was a consensus within the group on the need for an international body that would serve as the forum to explore arctic research issues and develop cooperative research plans. The group recognized, however, that the participation of the Soviet Union as the largest Arctic country would be essential. A follow-up meeting took place in Oslo, Norway, in February 1987, in which representatives from the Soviet Foreign Ministry took part.

A breakthrough occurred in October 1987, when General Secretary Gorbachev, in a public speech (United Nations, 1987) in Murmansk, USSR, addressed some of the issues of scientific cooperation in the Arctic that had been raised in Oslo. He stated that "the scientific study of the Arctic is of immense importance for the whole of mankind. We have a wealth of experience here and are prepared to share it. In turn, we are interested in the studies conducted in other arctic and northern countries." He further suggested that northern countries cooperate in environmental protection, the study of ethnic characteristics of the indigenous populations, and the development of cultural links between northern nationalities. Each one of these statements represents a radical change in Soviet policy on arctic research. Finally, Mr. Gorbachev proposed that a conference be held in the Soviet Union in late 1988 "to coordinate research in the Arctic" and "study the question of setting up a joint Arctic Scientific Council." It should be noted that a major part of the speech was political, proposing the creation of a nuclear-free zone, the scaling down of naval operations in the surrounding seas, the establishment of joint enterprises for oil and gas production, and the opening of the northern sea route to foreign vessels.

A few months later, the Communiqué signed by President Reagan and Secretary Gorbachev at the conclusion of their Summit Meeting in December 1987 contained a paragraph addressing "the unique environmental, demographic, and other characteristics of the Arctic" and endorsing "plans and opportunities for increased scientific and environmental cooperation ... within an international Arctic Science Committee of states with interests in the region."

The next international meeting took place in Stockholm in March 1988, hosted by the Royal Swedish Academy of Sciences. It was attended by 29 scientists and science administrators from the eight Arctic countries. The main topics for discussion were the possible establishment of an international coordinating body and the identification of possible areas for research cooperation. Some sticky issues had to be negotiated regarding the structure and composition of such a body. Would the initial core of countries be limited to the five "Arctic Rim" countries, or to the eight "Arctic" countries with territory north of the Arctic Circle? Would membership be restricted to the "founding countries" or would it be open to any country with active research programs in the Arctic? What should be done to prevent understandings or disagreements between the two superpowers from dominating all discussions to the detriment of inputs from the other participating countries?

After exhaustive discussions, it was unanimously agreed that an International Arctic Science Committee (IASC) should be established as a nongovernmental body for international discussion and communication on science matters having to do with arctic lands, seas, atmosphere, space, and people (Royal Swedish Academy of Sciences, 1988). The Committee would include the natural and human sciences and deal with basic and applied research in all fields in which international coordination and cooperation is desirable or necessary.

The Committee would seek to determine priorities for arctic research, increase the efficiency and effectiveness with which scientific resources and facilities are used, improve cooperation and exchange between scientists, and foster interdisciplinary links in the study of the Arctic. It would further pay particular attention to the encouragement and coordination of international studies that benefit northern residents and the indigenous people of the Arctic. It would not compete with existing bi- or multilateral programs but, rather, would strive to complement them.

The "Conference of Arctic and Nordic Countries on Coordination of Research in the Arctic'," to which Mr. Gorbachev had issued the invitation in his Murmansk speech, took place in Leningrad in December 1988. It was attended by over 500 scientists, half of whom were from abroad. In addition to the plenary sessions, six parallel sessions were held to identify concrete research projects requiring international cooperation. The session titles were: (1) Upper Atmosphere and Near-Earth Space, (2) Terrestrial and Marine Ecosystems of the Arctic, (3) Air-Sea Heat Exchange and the Arctic Climate and its Changes, (4) Pollution of the Atmosphere in the Arctic Region, (5) Geologic Structure and History of the Arctic, and (6) Socioeconomic and Cultural Problems in the Indigenous People of the North. The proceedings of the conference were not yet available at the time of this writing. A listing of the specific topics proposed under each title is given in Table 1.

The discussions on the structure and composition of IASC are still in progress, but it is hoped that a formal signing of the Founding Articles for the Committee by the eight Arctic countries (the "founding countries") could take place in early fall. The difficulties that the drafting committee has to overcome are indicative of the political complexity of the task.

First, there is the question of the prerogatives of the Arctic countries versus the openness of IASC to all countries engaged in significant arctic research. There is no disagreement about the latter, but should the eight Arctic countries constitute the governing board of IASC, should they merely constitute an advisory body, or should there be no special role for these countries beyond that of de facto being the "founding countries?" At the domestic level, which organization in the US should be the adhering body? Until now, several governmental organizations were involved: the Arctic Research Commission, which started the whole process; the Interagency Arctic Research Policy Committee, the Commission's sister body within the federal government; and the Interagency Arctic Policy Group in the Department of State. But since IASC will be established as a nongovernmental committee, the National Academy of Sciences would be the logical representative body; it has agreed to play that role.

These questions are presently being ironed out. Once IASC is established, in the end it all will depend on how effectively it performs its functions of recommending priorities and coordinating cooperative research programs in the Arctic. The prospects for success are great. Exciting research topics have been proposed (Table 1). Important basic research questions related to the response of the Arctic System to global change and its role in global climate await urgent answers. Several large-scale international projects like the International Geosphere-Biosphere Program, the World Climate Research Program and the Solar-Terrestrial Energy Program have important components of research in the Arctic. Comparative research in the biomedical and social sciences is urgently needed to help the native people of the Arctic overcome

detrimental effects of sudden cultural change. Conducting internationally coordinated applied research and sharing the results will help make natural resource extraction a much safer operation for environment and people in all Arctic countries. Perhaps the biggest benefit of all: joint arctic research will help build and expand mutual confidence among the participating countries in all domains—not just in the Arctic, not just in research.

TABLE 1

Conference of Arctic and Nordic Countries on Coordination of Research in the Arctic

Topics Proposed for Cooperative Research

1. Upper Atmosphere and Near Space
   - Influences of Solar Variability on the Arctic Upper Atmosphere
   - Diagnosis of Space Disturbance Effects
   - Middle-Atmosphere Ozone and Minor Constituents during Solar Maximum
2. Arctic Ecosystems
   - Adaptation of Organisms to Arctic Conditions
   - Biogeographical Regionalization
   - Biological Diversity
   - Regularities and Changes in Migration of Marine and Terrestrial Animals
   - Protection of Biological Resources and Ecological Monitoring
3. Interactions between Ocean and Atmosphere; Arctic Climate Change
   - Energy and Mass Exchange between Ocean and Atmosphere
   - Modeling of Air-Sea-Ice Interactions
   - World Climate-Forming Processes; Interactions of Arctic Ocean with Adjacent Oceans
   - Monitoring of the Arctic Atmosphere
4. Geology, Geocryology, and Glaciology
   - Geodynamics of Lithospheric Plates
   - Deep Structure of Earth's Crust under the Ocean Bottom
   - Model of the Evolution of the Oceanic Lithosphere
   - Permafrost Dynamics
   - Reconstruction of Glacial History during the last Glacial-Interglacial Cycle
   - Mass Balance and Fluctuations of Existing Glaciers
5. Environmental Conservation
   - Air, Water, and Land Pollution and Pollutant Transfer and Transformation
   - Ecological Consequences of Toxic Substances and Oil Spills

- Exchange of Chemical Elements and Pollutants between Arctic Ocean and Adjacent Oceans
- Monitoring and Modeling of Arctic Ozone, Arctic Haze, CFC's, and other Trace Gases
- Minimization of Anthropogenic Impacts and Rehabilitation of Disturbed Ecosystems

6. Socio-Economic, Educational, and Cultural Problems of the Indigenous People of the North
   - History and Development of Culture under Present-Day Conditions
   - Medical, Demographic, and Genetic Aspects of Health
   - Combination of Modern and Traditional Sectors of the Economy
   - Socio-Economic Problems of Non-Indigenous Populations
   - Design and Construction of Arctic Buildings
   - Machinery, Materials, and Technologies Adapted to the Arctic
   - Long-Term Development of the Arctic under Conditions of Increasing Complexity of the Economic and Ecological Situation

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RELEVANCE OF INTERNATIONAL RESEARCH FACILITIES TO INTERNATIONAL STABILITY

by

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INTRODUCTION

The Twentieth Century, it can be argued, was the cradle of a triumvirate: modern science, the hope for a quantum jump in the quality of life and, the fear that the resilience and integrity of our planet may come to an inglorious end, perhaps even a fiery one.

Humanity, in simplest terms, is faced with only two problems: how to live in harmony with itself and how to live in harmony with nature. Cooperative endeavors, in general, and international scientific facilities, in particular, have contributed to the mangement of both problems. Cooperative endeavors can and must, in my opinion, do much more in each domain.

MAJOR WAR—NO LONGER A RATIONAL OPTION

Precisely 45 years ago, while a graduate student at Penn State University, I was recruited by Dr. Trytten, President Roosevelt's chief recruiter of scientists for the war effort, to join the Manhattan Project in the mountains of New Mexico. Only after arriving there was I told about the project and assigned to work on the use of chemical energy to assemble Pu (of which we had none, at that time) under conditions that would generate a large energy release. The purpose of the project was to build an atomic bomb, which, it was expected, would end the war, first in Europe and then in Asia. The European war ended before nuclear weaponry became available, but not so the war in Asia, where the power and horror and devastation of nuclear weaponry was demonstrated; and those were quite crude weapons by today's standards. Fission weapons were followed by thermonuclear ones and then by composites, each more devastating than the previous one. Slowly, almost imperceptibly, it began to enter the consciousness of mankind that, finally, major war cannot be a rational option for governments and for the people they serve.

Nonetheless, nuclear weapons will not go away, certainly not the knowledge of how to produce them or the materials from which they are manufactured. It also appears that these weapons have represented a powerful deterrent, especially for the superpowers, to avoid actions that have a significant probability of escalating to all-out war, but that came uncomfortably close, several decades ago, and on several occasions. It is, however, a fact that the last 40 years represent the longest time in modern history, a period dating back 350 years, that we have not seen a war involving the major world powers. Our 40-year preoccupation (and properly so) with the dangers presented by large nuclear arsenals has not been in vain. Although "deterrence" can never be fail-safe, I personally believe that premediated nuclear war is no longer a significant possibility. I also agree with those who argue that, during the next ten years, we shall see the spectre of chemical and biological warfare garner the same kind of concern that we have devoted to the possibility of nuclear war

because chemical and biological warfare have the possibility of being just as horrible and as global as nuclear warfare.

In addition, such weapons are far less expensive to produce and far easier to conceal. However, I am optimistic about the prospects for establishing control over biological and chemical weaponry, as well as over nuclear weapons. The reason for my optimism is that there is no viable alternative; and because the world is rapidly becoming aware of a global, common danger of vast proportions. The danger is not as acute as the mass destruction that would result almost instantaneously from full-scale nuclear war and soon from chemical and biological warfare but is equally as deadly to most living things in the long run. This common global danger can be identified as environmental degradation, which is growing apace with population and with the depletion of nonrenewable resources on an exponential scale.

Also, the instabilities generated by islands of affluence in a sea of despair are becoming increasingly apparent. Whereas the present century has been characterized by the desire and achievement of independence for nations and peoples, the next century will need to see much greater emphasis on interdependence and on international cooperation and collaboration on a scale never before envisioned. Whether we anticipated it or not, whether we planned it or not, international scientific facilities have shown how to achieve wide-scale cooperation. Such facilities have mainly served the intellectual domain, and this will, of course, continue to be fundamental to technological progress. But future international facilities will also have the requirement to serve the practical domain, and in particular, to invent and evaluate new technologies that can contribute to international security, in its broadest context, and for all people. We should continually remind ourselves of the saying that "we have not inherited this planet from our ancestors, we are borrowing it from our children."

INTERNATIONAL SECURITY

There is, fortunately, a growing realization that the security of any nation is inextricably coupled to the security of all nations. Most of the elements of national security are not substantially different from those of international stability. These include:

- Agricultural Security,
- Environmental Security,
- Energy Security,
- Economic Security, and of course,
- Physical Security.

These five securities are not only international, they are also interdependent.

Fortunately, attitudes in both the US and the USSR, in NATO countries and in Warsaw Pact countries, are dramatically different, in a positive way, from what they were only a decade ago. Confrontation, as a remedy for disagreements, was tried for four decades. Some will argue that it served a purpose; few will argue that the world in general, and the superpowers in particular, can afford to rely on this approach, economically, ethically, or militarily. There is a growing willingness to give cooperation a chance. Early this year the *Wall Street Journal* reported the results of a comprehensive survey conducted as a bipartisan venture by four major polling organizations. The results are fascinating and hopeful. For example, 56% of those surveyed now believe that the US economy is a greater threat to national security than are military

adversaries. When asked what they perceive to be the greatest national security problem in the US, the reply was "drug trafficking." In order of importance the US public wants its government to:

1. deal effectively with the drug problem;
2. reduce the trade deficit and improve competitiveness in the market place;
3. actively seek ways to cooperate with the USSR, not only in arms control;
4. spend less on the defense of other nations; and
5. hold defense spending at constant levels but reduce waste.

For the purpose of our discussion today, item 3 is of paramount interest. International scientific facilities have been a powerful vehicle for promoting international cooperation.

INTERNATIONAL PHYSICS FACILITIES

When one thinks of international physics facilities, CERN stands out as a shining example of what such facilities might look like and what they can accomplish.

I had my last extended discussion with I. I. Rabi about three years before he passed away. I had decided to step down as Director of LAMPF and devote some years to arms-control-related issues. With the possible exception of Niels Bohr, I believe that Rabi was the wisest person I ever had the privilege of meeting. On this occasion we talked about what it will take to achieve a world devoid of a significant probability of major war. His conviction was that only when the inhabitants of this earth are overwhelmingly convinced that societal goals and ambitions cannot be achieved through armed conflict, only then will the scourge of war be banished. And then he reminded me of why he worked so hard to get CERN established. It was not because of the great science that the facility could produce or the technologies it would spawn or the economic activity it would engender. It was because he believed that only such major cooperative activities would catalyze evolution of the environment necessary for solving problems without resort to violence and destruction. I believe he was right, as usual. I know of no one who believes that there is a danger of warfare among the nations that are responsible for CERN. This is not to imply that CERN is the only reason for this belief, but CERN has helped immensely.

Not quite 20 years after the second World War, I was asked to serve on a government commission that was the first, from the US, to visit nuclear facilities in the USSR. I remember visiting the Kurchatov Institute where the accelerator facilities and the instrumentation matched very well what we had at Los Alamos. I was told that, after the war, Professor Kurchatov persuaded Stalin to build a basic nuclear research capability second to none so that it could serve as a bridge to the west. I was much impressed by this story.

The Joint Institute for Nuclear Research in Dubna has served a similar purpose. Along the path trodden by CERN followed Fermilab. Its purposes had less to do with the issue of world peace than they did with the issues of national prestige, advancement of science for its own sake as a great intellectual endeavor, development of technology, and industrial competitiveness. However, Fermilab has evolved into an effective vehicle for international cooperation. It was responsible, at least in part, for the establishment of the US/USSR Joint Coordinating Committee for the Fundamental Properties of Matter. This Committee has been operating, without interruption, for more than a dozen years, and with impressive accomplishments. We have been meeting one year in the USSR and the next year in the USA to agree upon collaborations and exchanges in particle and nuclear physics mainly, but also in condensed-matter physics and in cosmology.

From a rather painful start, when it was necessary to translate the meeting proceedings from one language to another and back again before signatures were affixed, the meetings are now conducted in an easy, informal atmosphere with no evidence of mistrust on either side.

There are, today, a large number of facilities that serve an international clientele. There are major ones in Japan, Germany, France, Italy, Canada, and elsewhere.

But the facility I know most about is LAMPF. LAMPF construction was started in 1968 and completed four years later. It was approved by the US Congress as an open facility, even though it was situated on the premises of one of the two nuclear-weapons-design laboratories in the country. Through the years LAMPF has served as a base for thousands of scientists from more than a score of countries. The degree to which it has contributed to relaxation of international tensions is not quantifiable. However, even during the coldest part of the cold war, there were visits to LAMPF by Soviet scientists and also return visits by US scientists. I am pleased to tell you that the present Director of LAMPF, Gerry Garvey, is enthusiastically continuing the tradition of LAMPF as an international Lab. At the present time he is involved in a major experiment at a cosmic-ray facility in the Caucasus. A Soviet and US team is about to measure the solar-neutrino flux to very low energies.

Two anecdotes that are illustrative of the way international facilities can have a bearing on international relations may be worth relating. Soon after Gorbachev became General Secretary of the Communist party, I was invited to give a seminar at the meson factory site at Troitsk. I started my talk by observing that nothing we do in science will be helpful to humanity unless our two countries learn, rather soon, to live in better harmony with one another. I expected the usual silence that had traditionally followed such a political remark. I was surprised by the enthusiastic applause. I relayed this incident to Senator Pete Domenici and later heard that this anecdote made its way all the way up to the National Security Council and the President.

The second anecdote is perhaps even more dramatic. About eight years ago Mary and I were invited to spend some weeks in the Peoples Republic of China. Near the end of our visit, we learned that Vice Premier Fang Yi would like to see us in his palatial office in the Forbidden City. The meeting was delightful and lasted far longer than we expected. Towards the end, the Vice Premier invited me to suggest how the PRC could accelerate its efforts to catch up with the West in science and technology. I suggested that he consider identifying, each year, some hundreds of the most creative, most innovative young scientists and engineers and sending them to centers of excellence, not for a few weeks or months, but for one or even two years, so that they could immerse themselves not only in the frontiers of science and technoloby but in the environment that is conducive to the flourishing of science and derivative technologies. His reply was instant: "Very good idea, Professor Rosen. Will you accept some of these at LAMPF?" After explaining that there was a 21-day limit on visits to LAMPF, I told him that if he would nominate some scientists whom we know by their reputation, I would try to get that regulation altered. He did and I did, although it took one year to accomplish. The first long-term visitor to LAMPF was Professor Sun Kuxun, who is now Director of The Institute for Atomic Energy. Every year since then we have had long-term visitors from the Peoples Republic of China and they are a joy to have among us. They demonstrate the Judeo-Christian work ethic in a convincing way.

One cannot quantify the extent to which this kind of initiative reduces unwarranted fears, decreases tensions, and improves the climate for international relations, but it certainly helps.

My colleague, Dr. John C. Allred, puts it this way, "that it helps greatly is clear to all of us who have experienced these scientific interchanges. Scientific discussion is a neutral ground upon which what matters is not race or accent or color of skin. What does matter is the search for scientific truth done logically and with mutual good faith and trust. I believe these elements, good faith and trust, grow in scientific

collaborations to embrace other facets of the lives of scientists of all nations. Whatever the mechanism, interactive scientific collaboration is a powerful force for confidence building among nations."

NEW INITIATIVES

I have devoted the last three years trying to understand a variety of arms-control-related issues. I certainly applaud past and present efforts to decelerate the arms race, to seek verifiable ways to transform offensive to defensive postures, and to reduce the enormous stockpiles of weapons of mass destruction, and also conventional weapons, while maintaining stability.

To me, arms control is any activity that reduces the probability of war without sacrificing fundamental values, including freedom from fear and freedom from hunger. I have, however, become convinced that weapons-accounting procedures, alone, no matter how verifiable, will be inadequate to achieve the political, social, and military environment necessary for a peaceful world. It will certainly not address major requirements of international security, especially those related to energy and the environment. It therefore appears to me that the time has come to dramatically expand international scientific facilities so as to stimulate international cooperation on those major global problems that cannot be solved unilaterally or even bilaterally.

International CERN-type laboratories devoted to energy and the environment appear to be not only desirable, but also necessary to serve the twin goals of improving the psychological environment for arms reductions and the physical enviroment for life on this planet. Without such cooperation the environmental situation can only continue its accelerating deterioration, until it becomes irreversible.

How then does one achieve cooperation beyond what we have at present? One small step is being attempted here and now in Santa Fe with this international Conference.

Another avenue is to increase people exchanges on a grand scale. This could be done by using educational institutions that are only partially engaged during the summer months.

RESPONSIBILITY OF THE SCIENTIFIC COMMUNITY IN MATTERS OF INTERNATIONAL SECURITY

No less a person than Mikhail Gorbachev is on record as recognizing that the security of one nation cannot be achieved by making other nations insecure. He has, as no Soviet Leader before him, espoused the philosophy that national security is strongly coupled to international security. What is the responsibility of the scientific community in achieving international security? We, of course, have the same basic responsibility to work for peace and justice and freedom as does any other citizen. But, in my opinion, we have additional responsibilities as scientists. Of course, we must try to facilitate the thoughtful use of science and technology to improve the condition of humanity. But I agree with those who argue that we must do more to foster a peaceful world and to educate the people of this planet to the opportunities presented by science and also to the dangers of population growth, of escalating insults to the environment, of the depletion of the earth's resources, and of the misuse of technology.

As the world continues to increase its dependence on technology, it is essential that the world's people increase their literacy in science and technology. The scientific community has a heavy responsibility to help make this happen. International scientific facilities provide a vehicle for this endeavor.

In front of the US National Academy of Science, there is a bronze bust of Albert Einstein. Engraved on the marble base is the following quotation: "The right to search for truth implies also a duty. One must not conceal any part of what one has recognized to be true." Dr. Vannevar Bush, Director of Scientific Manpower during WWII, authored the book *Science, the Endless Frontier*. He quotes as follows from the closing paragraph of his final report to President Roosevelt: "on the wisdom with which we bring science to bear against the problems of the coming years depends in large measure our future as a nation." That statement is even more relevant today. I would only replace "our nation" with "our world."

CONCLUSIONS

International facilities have played an important part in expanding and keeping open a dialogue between east and west. The advent of *glasnost* has dramatically reduced inhibitions on communications and opened new opportunities for international facilities to facilitate the understanding and appreciation of common goals and common threats. This is accomplished through frank discussions in which real problems are identified and assessed while fictitious ones are laid to rest.

Concerns about energy, the environment, economic security, raw materials availability, etc., require more effective international cooperation. Scientific facilities have provided a training ground for such joint enterprises, in both the technical and sociological spheres. Finally, international science facilities can help to bridge the chasm between the experts and the nontechnical community, because the support of these facilities requires describing the purposes and goals and hopes of science to the general public, which must bear the burden of their support just as it enjoys the fruits of their progress.

It therefore appears that we should now consider greatly increasing our investment in international facilities to specifically address not only basic research but also practical issues, such as environmental pollution, energy production, resources depletion, weather modification, defense against terrorism, space exploration, and, of course, agricultural technology. A final example: it appears that far too little attention has been given to the role of the oceans in the ecology of our planet. If we define coastal areas as 200 miles in depth, we see that well over half of the world's population resides in just those areas. Global temperature changes of not many degrees have the potential for producing havoc. Is there a more important long-term goal than to understand that issue? Does it not merit a major international initiative? Even a major international facility?

THE INTERNATIONALIZATION OF NUCLEAR SAFETY

by

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The subject of nuclear safety is surely interlinked in many ways with the themes of this conference. In searching for co-operative activities that touch on global energy and environmental problems and on initiatives that relieve international tensions, the ongoing developments in nuclear power safety offer a number of successful examples.

Commercial nuclear power has been with us for more than 30 years, and with 26 countries operating plants in addition to 6 more constructing their first, there has been an ongoing global co-operation. The coinciding of Chernobyl with Glasnost, along with the increasing awareness of the benefits of common solutions to safety issues, have brought about an internationalization of nuclear safety. Although the main responsibility for safety rests with each operator and its government, a primary driving force expanding international co-operation is the transboundary aspects of nuclear energy, as vividly demonstrated by the Chernobyl accident. In this presentation we focus on the mechanisms already in place that foster co-operation in the nuclear safety area.

At the non-governmental level the recent meeting of electric utility executives in Moscow this May to inaugurate the World Association of Nuclear Operators (WANO) demonstrates their desire for further global collaboration to ensure safe operation. At the governmental level there are regional mechanisms as seen by the activities of the Nuclear Energy Agency of the Organization of Economic Co-operation and Development (OECD) and those of the Council of Mutual Economic Assistance (CMEA), the eastern counterpart to OECD, and by activities of the Commission of the European Communities (CEC). At the core of the intergovernmental level, the International Atomic Energy Agency (IAEA), established more than 30 years ago in Vienna, Austria, serves as the global mechanism to promote safety. But in many aspects of its work, coordinated planning is required with other bodies having worldwide membership, such as the United Nations Environment Programme (UNEP), the United Nations Committee on Effects of Atomic Radiation (UNSCEAR), the World Health Organization (WHO), the Food and Agriculture Organization (FAO), the World Meteorological Organization (WMO) the International Labor Organization (ILO) and the United Nations Disaster Relief Organization (UNDRO), to name some.

This presentation describes some of the more visible and growing mechanisms for co-operation at the IAEA, above all, those related to internationally agreed safety standards, to enhancing operational safety of the more than 400 existing nuclear power plants, to information exchange and assistance in emergency situations and to a wide range of international agreements now in place. In concluding I will touch on the subject of nuclear energy and the environment. Today's 430 reactors account for nearly 17% of the world's total electricity production. There is a pressing need at both the national and the international level for all parties in the ongoing energy debate to vastly improve the communication of factual and balanced information to the public and to the policy makers. Only in this way can the individual benefits as well as the real risks of each of the competing energy sources be better appreciated to assure that global environmental needs are met.

M. ROSEN

SAFETY STANDARDS

To begin with, let us look at safety standards for nuclear power where an internationally accepted frame of reference is now in place. Where matters clearly transcend solely national considerations, internationally recognized standards have served us well. Through the years, air, sea and rail standards have fostered safe transport practices worldwide. The same approach has been taken for nuclear power. In the early 1970's, as the number of facilities planned and under construction worldwide increased dramatically, the IAEA undertook the development of a comprehensive body of safety standards. Completed in 1985, the Nuclear Safety Standards (NUSS) programme produced sixty documents designed primarily for use by countries embarking on nuclear power programmes. Based on practices of those countries already advanced in nuclear technology, the five Codes of Practice cover the essential aspects of safety, that is, governmental organization, siting, design, operation and quality assurance. They are supplemented by 55 Safety Guides and constitute an internationally accepted frame of reference for the safety of nuclear power plants. Official French, Spanish and Russian versions have been issued.

The 5 Codes were recently revised to reflect current thinking and experience gained in accident prevention and management. We are also updating a select number of safety guides in siting, design and operations in view of major advances in the state of the art.

The NUSS documents are internationally non-compulsory, they are no more than recommendations to Member States. However, although not binding, they have been used to establish national regulations. For example, China, with its emerging nuclear power programme, is adopting the NUSS standards as the sole basis of its national regulatory requirement. Italy along with four other countries incorporated the quality-assurance documents into its regulations. In 1988 the IAEA General Conference re-emphasized its support through a resolution which states "The General Conference considers that the NUSS Codes are international guides for assisting states with a nuclear power programme in place, or in preparation, in the formulating and implementing of national regulations and in carrying out actions concerning the safety of nuclear power plants." The resolution also invites "Member States to inform the Agency, on a voluntary basis, whether or to what extent the relevant requirements of their national regulations are consistent with the revised Codes." The IAEA has received replies from the leading nuclear nations indicating the consistency of the safety approach now in place.

In a complementary effort, last year the Agency's 13-member International Nuclear Safety Advisory Group (INSAG), established in 1985, completed its pioneering work on the Basic Safety Principles for Nuclear Power Plants (INSAG-3). The self-standing document does not state any newly discovered concepts, but reflects the most advanced policies and practices being pursued at nuclear power facilities. The Basic Principles consist of a set of three ojectives and nearly 80 supporting safety principles relating to siting, design, construction, commissioning, operation, accident management and emergency response capability. The tone of the advisory group's report, which does not require formal approval by the IAEA's membership, is intentionally not regulatory, with "shall," "should," and "may" not in evidence.

INSAG has established realistic safety targets: for existing plants, the probability of severe accidental damage to a reactor or its nuclear fuel is 1 in 10 000 years of operation of a well-designed plant; for tomorrow's improved plants, the target is 1 in 100 000 per reactor year for a severe accident. Still, if the improbable were to occur, effective accident management and containment measures at these plants would reduce (by a factor of 10) the likelihood of significant environmental releases of radioactivity and the concurrent need for off-site emergency response. Indeed, the technology and experience base exists to meet these goals.

Standards alone are not sufficient for public assurance that the level of safety for nuclear power is higher than that for any other viable energy technology. They need to be vigorously applied by the designers, manufacturers, suppliers, and operating personnel of nuclear power plants. A qualified regulatory body can assure this. The IAEA is experimenting with "peer reviews" of national nuclear regulatory programmes. The peer-review idea was first proposed two years ago by the U.K., Ireland, and the Federal Republic of Germany.

There are precedents for peer reviews by international organizations, notably at the OECD which reviews economic policies and at the International Energy Agency which reviews energy policies. A typical regulatory peer review could require at most two Agency staff of a possible total of five on a given mission. The Agency's role would be primarily to co-ordinate the reviews by the invited experts, based both on mission results and related research. Following a request from Brazil, a peer review of the Government's regulatory process was performed in March by a group of high-level regulators from Italy, France and Canada. The team examined the status and independence of the regulatory organization and its review and assessment process, as well as the licensing, inspection and enforcement procedures.

OPERATIONAL SAFETY

But standards and regulations alone are not enough for safety. A shift in emphasis at the IAEA from the production of standards and guidance material to a focusing on operational safety occurred in the early 1980's as the number of nuclear plants in operation worldwide rose into the hundreds and plans for new units fell off sharply. Today, an integrated system of four components promotes a worldwide feedback of experience. The year 1982 saw the beginning of an International Incident Reporting System (IRS), followed in 1983 by the first Operational Safety Review Team (OSART) visit. An Operational Safety Performance Indicator Programme (OSIP) emerged in 1985, and late 1986 saw the first mission of an international team solely for the Analysis of Safety Significant Events (ASSET) at a nuclear power plant.

The IRS facilitates an international exchange of factual information about nuclear power incidents and malfunctions. It is the only one in existence today that is worldwide, with 24 of the 26 nuclear power countries reporting directly, or for some OECD members, through the Nuclear Energy Agency's (NEA) system. Taiwan which is not an IAEA Member State and South Africa currently do not participate. The IRS can function in cooperation with regional schemes as is done with NEA, with which it currently exchanges reports and convenes joint meetings. A two-fold approach exists; first, to assist countries in establishing and harmonizing their national systems and secondly, for reporting events so as to identify underlying and common problems. Country co-ordinators submit national reports and receive copies of all other reports for further official distribution only. Although more active participation is desirable, the 169 reports received in 1988 brought the database to more than 600 incidents. The USSR has supplied 40 of the almost 100 reports from CMEA countries. The goal is to receive from each reactor those safety significant events that are estimated to occur at an average frequency of 0.5 to 1 per year.

In a complementary activity, the Agency makes available on request specialized investigative teams to conduct on-site in-depth analyses of operational experience and safety-significant events to determine the root causes of operational incidents. The first visit of such an ASSET solely to assess safety significant events was made to the Krsko nuclear power plant in Yugoslavia in November 1986. Six international experts highly qualified in analysis techniques, and in both the technical and human aspects of operation, tested methodologies for future worldwide application. A recent mission which focused on the effectiveness of the surveillance and maintenance programme visited the Brazilian Angra plant in November 1988, and

pre-visit discussions are currently in progress with Spain, with Pakistan for the KANUPP reactor at Karachi, and with the USSR for the Ignalina station in Lithuania, which has the world's largest power reactors; two 1 500 MW units of the RBMK type used at Chernobyl.

Turning now to OSARTS, an increasing number of national authorities and utilities are requesting these Operational Safety Review Teams, which were first offered in 1983. Typically, a team consists of a dozen highly experienced safety and operational specialists recruited from nuclear power plants, utilities, and government regulatory bodies around the world. Each review takes three weeks on-site with its findings submitted officially to the requesting authority. These missions are being carried out at a rate of one per month, and by year-end a total of 40 reviews will have been carried out in 21 countries.

OSART missions visited the large Soviet site at Rovno late last year and will conduct a pre-operational review this summer at the nuclear district heating plant near Gorky. By 1990 the programme will have reached almost all countries in the east and west, industrialized and developing. The effectiveness of the programme in extending international co-operation in nuclear safety is attested to by the participation of more than 250 experts and observers from 31 countries. The recent review in May of the Byron nuclear power station in Illinois was carried out by experts recruited from Argentina, Belgium, Canada, Finland, German Democratic Republic, Federal Republic of Germany, Japan, Sweden, and the USSR, together with IAEA staff members and observers from Brazil, Czechoslovakia and Mexico.

A report made available extensively to operating organizations and regulatory bodies worldwide summarized, the significant observations from the first 18 missions to 12 countries during the period August 1983 to May 1987, and a second report covering visits completed through 1988 was recently made available.

OSART reviews have shown the need to supplement subjective evaluative methods, and the fourth component of the IAEA's operational safety activities was initiated in 1985 to develop numerical or more quantitative operational safety indicators. While there is not yet international consensus on a single set of indicators, there is a clear trend toward their use even in developmental form by organizations at the plant, national and international levels. An initial set agreed upon by US and European utilities have involved indicators defined in more operational terms and cover items such as plant availability, radiation exposure and readioactive waste produced.

Experience from the IAEA's operational safety indicator programme (OSIP) suggests that although the areas of worker safety, environmental protection and operating reliability are well covered, the fundamental area of reactor safety is not well tracked. For example, direct assessments of safety and support system reliability are not generally being done.

The four operational safety programmes of the IAEA reflect the readiness of countries to co-operate more closely. While the OSART programme has become the more visible and rapidly expanding one, all four are expected to continue for the foreseeable future, supporting each other, and adapting to changing demands. Operational programme highlights of this year at the IAEA are the first OSARTs to China, CSSR, UK and Poland, the September joint annual NEA/IAEA review of IRS reports in Paris, the upcoming ASSET visits to Pakistan and the USSR, and an Open Workshop in Vienna to exchange international experience on safety indicators.

One final comment concerning operational safety that is not related to nuclear power. Efforts to enhance safety at the 335 operational research reactors in 56 countries take on added importance because more than 60% of these reactors are now at least 20 years old. From 1981 to 1988 the Agency has performed 50 safety assessments of research reactors in 23 countries. For many, modification is a crucial issue, whereas particularly in the developing world, there are concerns with safety in siting and design of reactors currently

being built. Until recently, there has been little formal safety guidance available to help national efforts. Thus, in addition to revising the existing Code of Practice (Safety Series No. 35) for the safe operation of research reactors, we are are actively preparing safety publications addressing modifications, siting, design, and emergency planning.

INTERNATIONAL CONVENTIONS

Information Exchange and Assistance

The growing internationalization of nuclear safety has also resulted in a wide range of international agreements covering the early notification of a nuclear accident, multinational assistance for a radiological emergency, civil liability for transboundary damage from nuclear accidents, and the physical protection of nuclear material.

The Convention on Early Notification of a Nuclear Accident was adopted in September 1986 and became effective a month later. It has been signed by 72 States. The Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency was also adopted in September 1986 and became effective in February 1987. It has been signed by 70 States. These Conventions serve as an international framework for providing information and assistance in the event of a nuclear accident or radiological emergency. Both the States that are Parties and the IAEA have specific responsibilities under these Conventions.

Under the Notification convention the IAEA has two main functions: to pass on immediately to other countries notification of the occurrence of a nuclear accident and its location, and promptly, as requested, to provide relevant information to minimize the accident's radiological consequences. The Agency must also maintain an up to date list of competent national authorities and relevant international organizations and their points of contact.

To meet its responsibilities, the IAEA has set up a 24-hour Emergency Response System to receive notifications and information and to disseminate them. The system was formally put into operation on 18 January of this year. Communications can be by telephone, telex, and telefax as well as through the Global Telecommunication System or GTS of the World Meteorological Organization (WMO). For point-to-point transmission of relatively short messages, such as the initial notification of an accident, the more conventional modes of communication seem best suited. The GTS would provide for simultaneous transmission of voluminous meteorological or radiological data to many countries. Special message formats and data-entry procedures needed for the GTS have been developed and communication systems are preiodically tested.

Under the Assistance Convention the IAEA has resources for the initial assessment of an emergency, can forward requests to other States and organizations, and can co-ordinate any assistance provided. The Agency is compiling information on experts, equipment, materials, and services that could be made available by countries and international organizations. It can also help to prepare emergency plans and needed legislation, to develop training and monitoring programmes and to evaluate monitoring systems.

The Brazilian Government was the first to invoke the Assistance Convention in requesting assistance through the IAEA, in responding to the radiological emergency in Goinia in 1987. The Agency arranged for assistance of two experts from the United States, for experts through the IAEA technical co-operation programme, for dosimeters, and for other monitoring instruments from France, the Federal Republic of Germany, Hungary, Israel, the Netherlands and the United Kingdom. Several countries, including Argentina,

France, the Federal Republic of Germany, Israel, the Soviet Union, the United Kingdom, and the USA provided other experts and equipment directly to Brazil. In another situation in February of this year, El Salvador requested technical assistance in handling an accident involving over-exposure of three persons working at a commercial irradiation facility. Although not a signatory to the convention, the assistance provided by the Agency was co-ordinated through the Emergency Response System. During last year's Cosmos 1900 re-entry, the USSR had also notified the Agency that they would invoke the notification convention if needed.

Nuclear Damage Liability

Where accident prevention and mitigation have not succeeded in preventing damage from nuclear installations, a comprehensive liability regime and an obligation to provide compensation for nuclear damages is an important component of what can be referred to as a nuclear energy safety regime. In the field of civil liability, the 1960 Paris Convention on Third Party Liability in the Field of Nuclear Energy open to OECD countries, and the 1963 Vienna Convention on Civil Liability for Nuclear Damage have long operated in isolation from each other. A Joint Protocol that establishes a link between the two Conventions was adopted by consensus at a Diplomatic Conference, jointly organized by the IAEA and OECD/NEA, in Vienna on 21 September 1988.

The new Protocol has been signed by twenty States and extends to them the coverage of the two Conventions. It also resolves potential conflicts of law that could have resulted from the simultaneous application of the two Conventions to the same nuclear accident, notably in the case of international transport. The conclusion of the Joint Protocol constitutes a landmark in the efforts towards the establishment of a comprehensive liability regime.

The work, however, is not yet complete. In 1986, the IAEA began consideration of the more difficult question of state liability for nuclear damage in an effort to establish better protection to potential victims of a nuclear accident. Most recently the IAEA General Conference adopted a resolution in which its Board of Governors was requested to continue as a matter of priority its consideration of the various aspects of liability and to convene an open-ended working group, which had its first meeting last month.

Physical Protection

A Convention on the Physical Protection of Nuclear Material, which entered into force in February 1987, has 47 signatures. During 1988, a further three States formally ratified it and became parties to the Convention, bringing the number at the end of 1988 to twenty-five. Although the Agency has depositary functions, it has not been assigned any direct responsibility regarding national measures taken to prevent unauthorized possession of nuclear materials. The Convention requires notification, directly or through the Agency, of the central authorities and points of contact responsible for physical protection and for co-ordinating operations in the event of any unlawful acts. The Agency maintains a current list of these contact points. As required by the Convention, a conference to review its implementation and the adequacy of its provisions is scheduled to be held in 1992.

OTHER ACTIVITIES

At the IAEA, other activities have been initiated aimed at further reducing the risk of serious accidents and limiting their possible consequences. The Agency is playing a role in ensuring the adequate training of operating personnel, in better understanding the man-machine interface, in the harmonization of intervention levels for food, in developing accident management techniques, in assessing accident risks through probabilistic techniques, and with increased priority in encouraging an ongoing discussion of improved safety features and of advanced nuclear power systems. These are only a few of the more than 30 individual projects currently under way in nuclear safety and radiation protection.

RESTORING PUBLIC CONFIDENCE

And finally, in closing, a few comments about nuclear energy and the environment and the pressing need to vastly improve the flow of factual and balanced information to the public and to policy makers. A real priority task today for those in the international nuclear community, which includes the IAEA, is to make a much greater professional effort to explain in understandable terms why they see nuclear power as a safe and acceptable energy source for the future.

Commercial nuclear power has been with us for over 30 years. The 430 power plants of today, which supply 17% of the world's electricity, have accumulated 5 000 years of operational experience. Their established record of successful performance is marred by a single accident which has led to consequences from radioactive releases.

There is no doubt that the economic and social effects of Chernobyl were severe, but these as well as the health and the environmental impact must be put into balance with other grave industrial accidents. The direct health consequences did not approach the level of the chemical industry's accident at Bhopal where over 2 000 people lost their lives and one hundred thousand were affected, many with long-term health effects. Nor did they approach the level of the 15 000 dead from a dam burst in India the same week of the Three Mile Island accident, or even of a recent dam failure in Italy which killed several hundred. Nor did they approach the annual death toll in coal mines, or in several notable off-shore oil rig catastrophes such as the one off the coast of Scotland, which resulted in more than 100 deaths. These comparative facts do not argue for complacency, but may serve as one frame of reference.

As to the long-term health impact of Chernobyl, the results of current authorative estimates show that the average additional radiation dose to people in Europe outside the USSR was within the range of the differences in natural background radiation between various European locations. No single individual is likely to have been subjected to a dose greater than a few times that received every year from natural radiation, and no individual's lifetime risk has been changed to any significant extent by the accident. In the southern part of the FRG where rainfall resulted in above average exposures, the population received an additional one-fifth of the dose incurred that year from natural radiation, the additional amount equivalent to less than a year's typical medical exposure. The one-time Chernobyl accident will have added the equivalent of 21 days to this generation's total lifetime exposure from radiation. In the Soviet Union only a long term epidemiological study can try to tell us the real consequences, but we know the number of additional cancer cases will be an exceedingly small and probably undetectable percentage of the millions of cases occurring during the same period due to other causes.

It is of no comfort to add that the environmental fallout from Chernobyl may be matched by the poisoning of the Rhine River two years ago from 10 tonnes of toxic chemcials washed into the waterway. Both events must remind us of the ever-increasing need to protect the environment from the effects of industrialization.

However, nuclear in its day-to-day operation, unlike fossil plants, generates power without emitting sulphur dioxide, nitrogen oxides, and carbon dioxide into the atmosphere. If the electricity that was generated by the world's nuclear power stations last year had been generated by the burning of coal, it would have resulted in an emission of about 1 600 million tons of $C0_2$ or an additional 10% to the $C0_2$ emitted from existing fossil plants. The average individual dose received each year from nuclear power production is only a tiny fraction, 0.006%, of that received from natural and medical sources. As for wastes, nuclear wastes are minuscule in volume compared to the wastes of fossil fuels and can be isolated almost in their entirety from the biosphere. A number of comparative studies convincingly show that among the principal fuels for electricity generation, when the entire production cycle from mining to waste disposal is considered, nuclear is the most benign, with the lowest adverse impact on human health and the environment.

Each energy source has some negative effects. With a concerted international attention to balanced and factual information, the decision makers may objectively weigh all advice. Their answer to the question "why nuclear?" may then be that nuclear power is acceptably safe, nuclear power is environmentally desirable, and nuclear power can be a stable component in a well-balanced energy mix of the future.

US-USSR COLLABORATION IN HIGH ENERGY PHYSICS

by

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INTRODUCTION

This discussion will be divided into four major sections:

1. High-energy physics and how it is carried out
2. History of US-USSR collaboration in high energy physics
3. Experiences, benefits, prospects

HIGH-ENERGY PHYSICS, HOW IT IS CARRIED OUT, AND INTERNATIONAL COLLABORATION

High-energy physics is the study of the basic structure of matter and the forces involved between the constituents. It is pure fundamental research with no immediate military or commercial significance; all results are published in the open scientific literature. Because of this, it is an ideal field for international collaboration. At Fermilab, for example, there are typically about 1300 physicists and graduate students on our approved experiments at any time, of which some 400 are from institutions outside the US, from about 20 countries.

High-energy physics experiments are carried out at accelerators, large central facilities at government funded national laboratories. There are a limited number of such facilities, due to their large cost—Fermilab cost about one quarter of a billion dollars twenty years ago. The research is carried out largely by professors and their students from universities. The size of research groups varies from one or two people to about 300 scientists, together with engineers and technicians, on a $100 million detector, with the experiment lasting a total of about ten years. A research group is composed of up to 30 university subgroups, each responsible for a piece of the detector or software, with all subgroups sharing in the physics results. The subgroups get together to carry out an experiment because of a common interest in the physics goals; this leads to collaborations with physicists from many countries. The experiment is carried out at the accelerator that best suits the experiment, in whichever country it is located. Some years ago the directors of the major laboratories issued a statement that the criteria for acceptance of a research proposal are the scientific merit and technical competence of the proposal; note that there is no mention of the country of origin of the experimenters.

HISTORY OF US-USSR COLLABORATION IN HIGH-ENERGY PHYSICS

US-USSR collaboration in high-energy physics started in 1966 with the first USSR physicist coming to work at a US institution. Individual US physicists visited the USSR in the period 1970-74, while the first US group to carry out a (collaborative) experiment in the USSR started its activities there in 1970. In 1972, the first USSR group came to the US. Since that time, cooperation has increased each year and appears to have been unaffected by the state of political relations between the two countries.

Cooperation in high-energy physics was discussed in meetings between President Eisenhower and Secretary Kruschev in 1955 and 1960, and led to a memorandum of understanding in 1960 between the US Atomic Energy Commission and the USSR State Committee for the Utilization of Atomic Energy. In 1973, the "Nixon-Brezhnev" agreement on Cooperation in Peaceful Uses of Atomic Energy was signed. At the third meeting of the committee set up to coordinate that agreement, in 1975, there was established the US/USSR Joint Coordinating Committee for Research on the Fundamental Properties of Matter (JCC-FPM). The JCC-FPM meets each year, alternately in the US and the USSR, with about 8 delegates from each country. In the US side are representatives from universities and national labs active in high energy physics, with organization and the chairman of the delegation from the Department of Energy.

The annual JCC-FPM meetings discuss the collaboration for the forthcoming year and produce a record containing the agreements reached on the numbers and duration of the planned visits for the collaborative research projects. As an example, at the 1988 meeting, the plans for 1989 contained 1042 man-weeks of USSR physicist time in the US (of which 685 were at Fermilab), and 358 man-weeks for US physicists in the USSR. These numbers are a guide to activities for the forthcoming year and can be modified by mutual agreement between the sending and receiving institutions. Generally the time spent by USSR physicists in the US is significantly higher than that of US physicists to the USSR; a major reason is that at the present time the highest energy accelerators, and thus the forefront activities of the field are in the US.

US-USSR COLLABORATION ACTIVITIES AT FERMILAB

Fermilab has had a tradition of extensive collaboration with USSR physicists since its experimental program started in 1972; the first experiments using the accelerator were US-USSR collaborations. Out of a total of 383 approved experiments at the Laboratory, 27 have had physicists from USSR institutions, involving a total of 136 USSR physicists; on 7 of the experiments, the spokesperson (senior physicist on the experiment) was from the USSR.

At any given time, there have been an average of around ten USSR physicists at Fermilab, with the numbers depending on the details of the Laboratory experiment schedule. The physicists stay at the Laboratory for periods of time ranging from 1 day to 2 years; for the longer stays, a spouse frequently accompanies, and often younger children. Generally, they stay in housing on the Fermilab site, identical to that of other visiting physicists and their families. Since 1972, some 400 USSR visitors have been at the Laboratory, some having made several visits. As an illustration of the extent of Fermilab's USSR activity, Appendix I shows the USSR visits to the Laboratory that have been made, or are currently expected, in 1989. The total is over 70.

EXPERIENCES, BENEFITS, PROSPECTS

1. What has the USSR gained by this collaboration?

   A major gain has been the ability of USSR physicists to carry out physics research at the highest-energy accelerators in the world, which currently are in the US. The scientists gain some view of US technology, although that can be obtained also at other major laboratories in Western Europe and Japan. They also see US management techniques, style of working, and reduced bureaucracy compared to conditions in their own country.

2. What has the US gained by this collaboration?

   Many excellent USSR physicists have worked on experiments here, helping to further the field and interacting with our own physicists. The US has had the use of new and novel equipment invented in the USSR; two examples are a hydrogen gas jet target, which was the central component of the first Fermilab physics experiments, and a lithium lens essential for antiproton production for the Fermilab Collider.

   The USSR physicists bring with them to the experiments state-of-the-art equipment built in their laboratories, which would otherwise have to be purchased with US funds. In 1984, for example, there was over $5 million worth of such equipment at Fermilab; in 1990, the amount is expected to be greater. Obviously, we gain some view of the state of USSR technology.

3. Mutual benefits and prospects.

   There are many benefits on the human level, which can only be helpful to relations between the two countries. Contacts made in joint efforts often lead to close friendships. US scientists become better informed on life and attitudes in the USSR; likewise, USSR scientists (and their families) experience US life firsthand, and return, presumably to tell their colleagues.

   Obviously there are small problems in activities of this nature, but they are not severe enough to have significant impact. The exchanges tend to be a little more formal than necessary, which probably stems from the needs of the USSR bureaucracy. Also, most US physicists find travel and living in the USSR more difficult than they are used to in US or Western Europe.

   In spite of the negatives, over the years the collaboration has been growing, and all indications are that it will continue to grow; the consensus is that it is beneficial to both sides.

APPENDIX I

	NAME	INSTITUTION	LENGTH OF STAY (Weeks)
E704			
	N. Belikov	IHEP	12
	O. Grachyov	IHEP	12
	Y. Antipov	IHEP	6
	Y. Pitchalnikov	IHEP	6
	A. Vassiliev (+w)	IHEP	34
	A. Metshanin	IHEP	26
	A. Derevschikov	IHEP	8

	V. Solovianov	IHEP	13
	V. Rykov	IHEP	17
	N. Mikhalin	IHEP	17
	S. Nurushev	IHEP	3
D0			
	A. Peryshkin	Novosibirsk	13
	A. Dokshin	Izhora	8
	A. Vassiliev	Izhora	8
	E. Kistenev	IHEP	8
	A. Kholodenko	IHEP	17
	V. Ryadovikov	IHEP	17
	P. Mamakov	IHEP	2
	S. Denisov	IHEP	2
	D. Denisov	IHEP	4
	V. Sirotenko	IHEP	4
	V. Koreshev	IHEP	4
P Source			
	T. Vsevolozhskaya	Novosibirsk	4
Miscellaneous			
	V. Fadin	Novosibirsk	1 day
	M. Ryskin	LNPI	1 day
	V. Abramovsky	Georgia A.S.	1 day
	O. Kanchelli	Georgia A.S.	1 day
	L. Jenkovszky	ITP Kiev	1 day
	N. Tyurin	IHEP	1
	P. Bogdanov	SCUAE	1
	A. Agafonov	Lebedev	1 day
	A. Drozhdin	IHEP	1 day
	I. Issinskiy	Dubna	1 day
	E. Krastelev	Lebedev	1 day

USSR VISITORS TO FERMILAB - 1989

	NAME	INSTITUTION	LENGTH OF STAY (Weeks)
Accelerator			
	N. Mokhov (+w +c)	IHEP	18
	S. Goloborodko	IHEP	11
	Y. Chernousko	IHEP	17
	V. Komarov	IHEP	2
Theory			
	I. Dremin	Lebedev	8
	Y. Makeenko	ITEP	8
	V. Peskov	IPP	1
	S. Troshin	IHEP	4
	M. Voloshin	ITEP	1
	M. Shifman	ITEP	1
	N. Nikolaev	Landau	2 days
Astrophysics			
	A. Dolgov	ITEP	8
	V. Rubakov	INR	2
	A. Linde	Lebedev	1 day
E761			
	N. Terentyev (+w)	LNPI	48
	L. Uvarow	LNPI	23
	I. Tkatch	LNPI	23
	A. Vorobyov	LNPI	4
	A. Denisov (+W)	LNPI	22
	V. Grachov (+W)	LNPI	22
	A. Khanzadeev (+w)	LNPI	22
	V. Golovtsov (+w)	LNPI	22
	N. Bondar	LNPI	22
	V. Samsonov	LNPI	4
E672			
	V. Abramov (+w +c)	IHEP	48
	Y. Kirillin	Efremov	1 day
	G. Kenov	RTI	1 day
	G. Mamaev	RTI	1 day
	A. Mirzoyan	INR	1 day

RUBINSTEIN

	NAME	INSTITUTION	LENGTH OF STAY (Weeks)
E672 cont.			
	A. Pashenkov	INR	1 day
	V. Piskunov	ITEP	1 day
	Tishin	IHEP	1 day
	V. Skachkov	ITEP	1 day
	A. Tumanyan	ERPI	1 day
	I. Shukeilo	Efremov	1 day
	P. Chirkov	IHEP	1 day
	V. Balakin	Novosibirsk	1 day
	V. Shemelin	Novosibirsk	1 day
	V. Shiltcev	Novosibirsk	1 day
	V. Shirokov	Novosibirsk	1 day

U.S.-U.S.S.R. COOPERATIVE EFFORT IN RADIOACTIVE HIGH-LEVEL WASTE MANAGEMENT

by

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INTRODUCTION

Confidence-building measures play a role in aiding to defuse crises and reduce the escalatory risks inherent in crises. By participating in confidence-building measures, nations enhance their national security. In the past, confidence-building measures have mainly operated in the political arena. However, there is a need to develop initiatives to function, not only in the political arena, but also in the social arena. We meet to advance these shared-interest programs which can strengthen mutual trust in nonpolitical endeavors. Cooperative efforts can play a significant role in improving superpower relations by facilitating better communications which hopefully can result in more constructive interaction in areas such as arms control.

This paper proposes a U.S.-U.S.S.R. cooperative effort in prototype disposal demonstrations, and in safety assessments of potential repositories for radioactive high-level wastes (HLW). It should be clear that the problem of HLW is a shared-interest problem for the following reasons:

1. No other nations employ as many nuclear reactors for the generation of electricity as the United States and the Soviet Union. The United States has 100+ operable commercial reactors producing 100GWe, which is 17 percent of the U.S. total output. The Soviet Union has 50+ reactors producing 35 GWe, or 11 percent of their total output.[1] Both nations have over three decades of experience in nuclear generated electricity production, as well as three decades of attendant nuclear reactor wastes.
2. Because uranium and plutonium are also present in irradiated fuel (spent reactor fuel), those nations which produce nuclear materials for defense weapons have reprocessing facilities to recover these materials. The United States and the Soviet Union possess the largest quantities of nuclear weapons. In the United States, these Department of Energy uranium and plutonium recovery processes generate HLW in the form of an aqueous stream. These liquids are reduced in volume and some of the remaining materials must eventually be isolated from the biosphere until they have decayed to levels that will present no unacceptable risk, perhaps for as long as 100,000 years.

It is recognized that both nations possess the technical and economic resources to individually solve this problem. In some respects, the specific problem of HLW conditioning, the first step in disposing of existing HLW, has been solved to the satisfaction of several nations. France, the United Kingdom, the Federal Republic of Germany, Belgium, and Japan have all operated fuel reprocessing plants which generated HLW.[2] What has yet to be solved is the choice of safe final disposal–the choice of the stable waste form, corrosion resistant packaging, engineered barriers (to be incorporated into the vault repository), and geologic medium–a systems concept that minimizes the transfer of radiologically significant nuclides to man.

PROPOSAL

This paper proposes a cooperative U.S.-U.S.S.R. effort in: (1.) prototype HLW disposal demonstrations to verify operational safety and address technical questions that can only be answered in large- scale experiments; (2.) safety assessments to predict the behavior of the wastes in interesting scenarios by analyzing the performance of each barrier of a multi-barrier system.

Cooperation is intended to be more than the routine exchange of data. Cooperation is envisioned as the exchange of:

- Scientists and technicians between sites where prototype demonstrations are carried out in both countries,
- Mathematical models and computer codes for isolation of the radionuclides, and analysis of the pathways through the geologic media being considered by the two nations,
- Techniques for further reducing waste volumes,
- Designs for canisters, casks, instrumentation and remote handling equipment, and
- Concepts for robotic devices.

The objective of this cooperation is to pool efforts in order to maximize respective technical achievements and expertise while minimizing the duplication of efforts.[3] Because of the technical resources both nations possess, the synergy resulting from the integration of U.S. and U.S.S.R. research programs should be large. The confidence and trust promoted by exchanging scientists, codes, techniques, and designs should also be great, as individuals work together to solve a shared-interest problem.

BACKGROUND OF THE PROBLEM

Following World War II, the United States began investigating ways to use nuclear energy for peaceful purposes, as well as to extend the nation's weapons capability. In 1951, electricity for commercial use was generated from nuclear reactors for the first time in the United States. In 1955 the submarine Nautilus went to sea powered by a nuclear reactor. Since the energy from nuclear fission is millions of times that from burning coal or oil, the rush to build nuclear reactors that might produce low-cost power began in the mid-1960s. The four-fold increase in the price of petroleum in 1973 intensified the growth of the industry, particularly in Europe. By mid-1987 there were 418 operable reactors in 34 countries. [4]

For nations with few natural energy resources, nuclear reactors provide the potential for a moderate-cost, domestically-fueled energy source. Reprocessing and recycling of uranium and plutonium are the equivalent of domestic "in-house coal mines and oil wells." In Japan, with 40 reactors, the energy consumed annually is 25 times the equivalent energy produced from domestic fossil fuels. In France, with 50 reactors, this energy consumption multiplier is 10, which is no surprise since 70 percent of the electricity produced in France is nuclear generated.[5] Nations such as the Soviet Union, which possess both sufficient stocks of fossil fuels and economical hydro resources, also utilize nuclear power stations when natural energy resources are located at great distances from industrial and urban concentrations.

Options

Setting aside the problem of defense-generated wastes, the decision tree for managing spent fuel from commercial power reactors has only two options. One can reprocess the spent fuels to recover uranium and plutonium and dispose of the conditioned wastes, or one can plan for the direct disposal of spent fuel elements. The appropriate option is that which is technically feasible, economically preferable, and socially and environmentally acceptable. Within the decision tree, a "pseudo-option" exists to store spent fuel elements for 10 to 100 years while technology is further pursued for possible solutions. "Long-term surface storage substitutes the institutional requirements of human care and maintenance for the technical requirements of geologic isolation."[6] Long-term storage simply puts off disposal decisions for another decade or century.

All three of these options ultimately require the encapsulation of the HLW fission products, or the spent fuel rods and fission products, into a solid matrix. Ideally, the solid produced for disposal should be highly concentrated, unleachable, insoluble, have high chemical stability and radioactive resistance, and good heat transfer characteristics and mechanical strength. At the present time, borosilicate glass is the first-generation material of choice.

All three of the options ultimately require the encapsulated materials to be placed in a geologic medium for isolation. Salt, clay, crystalline rock and sedimentary rock are candidates for repository siting. Most likely, all of these media are acceptable. However, since no nation has chosen a specific systems approach to the permanent disposal of HLW, the proposed cooperative U.S.- U.S.S.R. effort pledges essential research and development.

Spent Reactor Fuel Accumulations

Within the United States, the spent fuel inventory approximates 15,000 tHM (tonnes/heavy metal) and defense activity wastes approximate 350,000 cubic meters.[7] World-wide, excluding the Soviet Union, there are nearly 40,000 tHM discharged from nuclear reactors and in storage. Each year adds another 5000 to 6000 tHM to the spent reactor fuel inventory.[8] Spent fuel elements are usually stored underwater in deep pools near reactor sites for 5 to 10 years to reduce the decay heat from fission products. Some materials that have decayed sufficiently are removed from wet storage and placed in containers for dry storage.

Commercial Spent Reactor Fuel Reprocessing

Reprocessing of spent fuels has been accomplished in Belgium, France, the Federal Republic of Germany, India, Japan, the United Kingdom and the United States.[9] The most technically advanced and commercially successful operation is in France where 1000 cubic meters of high-level liquid waste have been vitrified and placed in canisters. New reprocessing plants with significant capacity are being built in the United Kingdom and in the Federal Republic of Germany. French plants are being enlarged to reprocess spent reactor fuel from European countries with spent fuel generation rates too small for economical reprocessing in national facilities (e.g. Sweden, Switzerland, Belgium, Netherlands, and Italy).[10] It should be acknowledged that several European nations have made very large financial commitments to nuclear power and to reprocessing and recycling. [11]

OBJECTIVES OF THE COOPERATIVE EFFORT

In the high-level waste management arena, "R&D has now reached a stage where it is necessary to verify the feasibility (of disposal) by means of large facilities which reproduce at full scale and in real geologic conditions the essential parts of a large and industrial disposal plant of the future." [11] A cooperative effort in prototype disposal demonstrations and safety assessments is proposed to address the multitude of technical questions that can only be answered in large-scale demonstrations.

Prototype Disposal Demonstrations

Since the United States and the Soviet Union will most likely have large numbers of nuclear reactors operating into the 21st century, and both nations will continue nuclear weapons production, both types of disposal options should be given equal consideration.

Some examples of objectives in the prototype demonstrations could be:

- Design and test of fail-safe emplacement and retrieval equipment (e.g. coring and cutting for emplacement and retrieval; shielded casks for emplacement and retrieval; transportation; floor/wall shielding covers;etc.),
- Preservation and analyses of package surface corrosion data,
- Design and test of thermal and radioactive decay instrumentation and analyses of data, and
- Analyses of the behavior of host and backfill materials.

Safety Assessments

Data analyses on a large-scale systems demonstration represent the only means of validating hypothesized safety assessment results. Analyses should provide sufficient factual information to make trustworthy management of radioactive waste a realistic objective.[12]

Some examples of objectives in safety assessments could be development and verification of models to examine the:

- Ability of multiple, relatively independent barriers (near field, host geologic media, and ecosystems) to isolate the waste radionuclides, taking scenarios of interest into consideration; and
- Pathways by which radioactivity could arise, and the effect on humans.[13]

Detailed models are needed to examine and relate the interaction of heat and stress in the canister package, and after the canister is breached, the leaching of radionuclides and their transport through the various geologic media to humankind. These models would embrace theories of nuclear physics, strength of materials, heat and mass transfer, geochemistry, chemical kinetics, thermodynamics, and other sciences. Codes to carry out these calculations will be numerous and complex.[14]

CONCLUSIONS

Within the United States and the Soviet Union, hundreds of complex and technically sophisticated models/codes have already been developed, and tens of thousands of technical papers written in regard to

disposal and safety assessments of high-level radioactive waste. Cooperation with the Soviet Union in this proposed effort would allow detailed comparison of vast amounts of technical data and information. It would also allow a pooling of resources and the potential to allocate further efforts to produce the synergy that comes from coordinated, rather than independent, research programs. Most importantly, cooperation with the Soviet Union could strengthen mutual trust in the political arena and improve superpower relations.

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BUILDING CONFIDENCE THROUGH US-SOVIET SCIENTIFIC EXCHANGES

by

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THE TRADITIONAL CONCEPT OF CONFIDENCE BUILDING

To arms-control specialists, the term "confidence building" has a distinct connotation based on years of effort in formal and informal arms control arenas to develop approaches that reduce the suspicions of the US Government and, to a lesser extent, the concerns of the Soviet Government, over hostile intentions of the opposing superpower. Beginning with President Eisenhower's open skies proposal in the mid-1950s through the current debates at the international negotiations in Vienna devoted to confidence building, American diplomats have emphasized the importance of measures designed to decrease the likelihood that the United States or the USSR would misinterpret "normal" peacetime military activities of the other country as activities being undertaken to set the stage for military attacks in the near future. They also have underscored the closely related objectives of building trust between the two countries and of reducing uncertainties and miscalculations in each country's assessments of the capabilities of the other.

Many types of East-West confidence-building measures have been considered in addressing these overlapping goals. Among those now incorporated in agreements are the communications hot line between the leaders of the United States and the USSR, the procedures for warning of accidental launches of strategic weapons and for notification of exercises of conventional military forces, and the verification provisions of the ban on intermediate-range nuclear weapons (INF Agreement). Other approaches that have also been proposed by Soviet or American scholars include nuclear-free zones, restraints on naval activities near coastal waters of an adversary, and a demilitarized corridor in Central Europe.

Secretary of State James Baker, like several of his predecessors, has used the shorthand descriptor of "transparency" to characterize confidence-building measures. Given the closed nature of Soviet society, at least until very recently, the US Congress, as well as the Executive Branch, has enthusiastically embraced this concept while American officials press hard in many international forums to reach agreements that would illuminate Soviet activities and thereby clarify their intentions.

On the other hand, the USSR has frequently charged that confidence-building measures are simply a ploy to legitimatize intelligence collection activities. Historically, the USSR has been far less enthusiastic than the United States in embracing the concept. In recent years, however, Soviet officials have been willing to reach agreements that allow Western access to previously closed Soviet military activities, and the verification procedures attendant to the INF agreement, in particular, represent a dramatic change from earlier Soviet preoccupation with protecting the secrecy of activities within their military establishment. Now, perhaps propelled to some extent by the winds of glasnost, the USSR has become an advocate of confidence building in the traditional arms-control context, and foreign access to military activities within the USSR and Eastern Europe attendant to both formal agreements and informal arrangements are becoming more commonplace.

THE CONTRIBUTION OF SCIENTIFIC EXCHANGES TO ARMS CONTROL

Now let us turn to the most important dimension of this conference, the role of scientists and scientific exchanges in enhancing the security of many nations. Scientists have been on center stage since World War II in efforts to decrease the likelihood of war. They know about the destructive power of nuclear weapons and missiles and the feasibility of controlling those devices that were products of their inventiveness. These scientists are also attuned to the benefits of scientific cooperation, both in advancing the state of science and in staying abreast of developments throughout the world.

Thus, for the past forty years the potential and limitations of scientific exchanges in contributing to progress in arms control have been common discussion topics both at intergovernmental negotiations and during scientific gatherings. Many governments have explicitly recognized exchanges in seismology, oceanography, nuclear physics, and space sciences as important steps in improving prospects for arms control.

Intergovernmental debates in Geneva and New York have welcomed such cooperation as a framework for specific arms-control measures. Also, the highly successful scientific cooperation in Antarctica was important in setting the stage for early arms-control verification activities initiated there.

Scientific cooperation is now being linked very directly to concrete arms-control proposals. For example, the US-USSR Cortex experiments to improve understanding of the reliability of techniques for measuring the yield from underground nuclear tests are an outgrowth of the negotiations of limitations on underground testing. Scientific exchanges in the fields of biology and chemistry are repeatedly cited as potential contributors to the implementation of future agreements to verify limitations on biological and chemical warfare activities.

At nongovernmental forums sponsored by the Pugwash Committee, the United Nations Association, the Academies of Sciences of many countries, and other organizations, scientific cooperation is heralded as a practical step toward improved international understanding. Discussions at these meetings often begin with commentaries on scientific exchanges that have a direct relevance to weapons developments, but rapidly the scope broadens to include almost every type of cooperation on the grounds that scientist-to-scientist contact can only contribute to improved prospects for peace.

THE CHANGING CONCEPT OF MILITARY POWER AND NATIONAL SECURITY

As we have noted, the concept of confidence building is rooted in a universal desire to reduce the likelihood of armed conflict, and particularly armed conflict between the superpowers, which could obviously threaten the national security of one or both countries. But now the definition of national security is changing. Not that military threats are not important; they simply are less of an overriding factor than in the past in considering national security concerns. Specifically, political confrontations among nations are increasingly rooted in economic disparities throughout the world and in frustrations over access to economic resources. American difficulties in Latin America and Soviet troubles in Eastern Europe, for example, are traceable in large measure to economic problems in these regions. Also, the growing economic interdependence among nations is vividly underscored by the fact that international financial transactions now involve transboundary transfers of more than one trillion dollars every day, and at the top of the current Soviet agenda are a variety of issues concerning eventual participation of the USSR in such activities, which are dominated by Western financial interests.

Disruption of global ecological systems due to pollution and to the ravaging of biological resources has been described by some scientists as a potential threat to survival of no less significance than the threat of nuclear war. Although the adverse impacts of changes in ecological systems will be felt only gradually, predictions of the eventual consequences of current trends in the buildup of greenhouse gases, for example, are dire indeed. Also, the AIDS virus raises new concerns over the safety of populations around the globe, and food shortages will take on unprecedented meaning if the droughts of recent years persist. In many of these areas, international cooperation can assist in clarifying and mitigating problems, and scientists can frequently play a pivotal role in such cooperation.

The concept of national security will continue to evolve, and many domestic and international political, economic, and technological factors will determine the well being—and hence the real security—of the populations of the United States and of all countries. Of course, strong linkages will remain between national security and military power; but as military power becomes less of a dominant force in determining the future course of nations, the importance of scientific exchanges will increase.

As we broaden our appreciation of the factors influencing future survival, we should also move beyond the traditional concept of confidence building and take into account this changing nature of national security. In particular, we cannot afford to ignore the importance of building confidence between those nonmilitary factions in the United States and the USSR that influence the broader national security interests of the two countries. For example, only a decade ago, suggestions that the Administrator of the US Environmental Protection Agency could influence the national security interests of the United States would have been considered very strange. Now, no one doubts the importance to global security of steps at home and abroad to moderate predicted changes in the global climate due to human activities. As these new players gain more influence in national debates over security, their sensitivity to the motivations of the other superpower in areas of mutual interest becomes significant.

THE CURRENT SCOPE OF US-SOVIET SCIENTIFIC EXCHANGES

The ever-growing stream of American and Soviet scientists being processed through the PanAm and Aeroflot counters attests to the recent upsurge in the scope of scientific cooperation between the United States and the USSR. This cooperation draws on American scientists from many types of institutions—from the Government, from industry, and from the academic community. Similarly, Soviet scientists from many institutions participate as exchange scientists, as hosts for visiting Americans, and as correspondents with American colleagues working on related scientific problems. These scientific interests range from studying the galaxies to investigating the polar ice caps, to comparing geological rift systems of different continents, to tracing the origins of acid rain, to enhancing energy conservation efforts, to combating the spread of viruses, to cataloging butterflies along the Alaska-Siberia frontier.

A relatively new aspect of cooperation is the many arrangements between American and Soviet commercial organizations that encompass some aspect of science or technology. Cooperation in science is usually designed to lead eventually to sales of products or licenses. However, many administrative and financial barriers—and particularly difficulties in converting ruble earnings into dollars for repatriation—inhibit moving from modest cooperation in research and feasibility studies to joint ventures and other ambitious commercial schemes.

Still, on the order of 100 cooperative arrangements now exist between Soviet and American commercial organizations. About fifteen joint ventures are in place. More commonly, cooperation includes licensing

agreements, joint research projects, joint seminars, and occasionally joint publications. Cooperation involves, for example, sensitizing the Soviet taste to the ever-secret formulas of Pepsi Cola, Coca Cola, and Fanta; introducing automation systems into Soviet fertilizer plants; improving the quality of nutritional supplements for animal feeds in both countries; applying unique Soviet medical instrumentation in American institutions; and marketing Soviet agricultural equipment in Wisconsin. Recently the Monsanto Company developed an interesting new approach, namely establishment of a joint research laboratory located in the Shemyakin Institute of Bioorganic Chemistry in Moscow.

For more than 25 years a number of US Government agencies have had formal agreements with counterpart agencies in the USSR involving exchanges in science and technology. The National Oceanographic and Atmospheric Administration wants to share in the fruits of the Soviet's massive collection of oceanographic data. The Department of Housing and Urban Development is interested in Soviet experience in construction in Arctic regions. The National Park Service hopes to learn from Soviet research in its extensive network of preserved nature areas. The Department of Energy and the Nuclear Regulatory Commission do not want to see another Chernobyl-type accident anywhere in the world and are prepared to help the USSR improve its nuclear safety programs. The National Institutes of Health plan to learn from Soviet experience in coping with alcoholism.

The Agreement between the two Governments in the environmental field has been a pacesetter for bilateral cooperation in recent years, involving dozens of projects directed to environmental planning, natural resource management, environmental pollution, and related topics. Soviet officials and scientists are belatedly awakening to the very severe unattended environmental problems in the USSR—the pollution of Lake Baykal, the drying up of the Aral Sea, the brown clouds over the Siberian cities, and the discharge of toxic wastes into waterways. They are interested in learning from American experiences. Although the United States is far ahead in most aspects of controlling pollution, cooperation has benefited American specialists in the development of new environmental assessment techniques, in relating pollution levels to ecological damage, and in broadening gene pools to help preserve rare plant species. Also, in addressing global issues, the Soviet are particularly adept in displaying their impressive mathematical modeling techniques.

As to the involvement of private American institutions in exchanges, most of the activities are now carried out directly between American scientists, universities, and professional organizations and counterparts in the USSR, with a surprising decline in the amount of orchestration (and financing) of these activities in Moscow and Washington. To be sure, the Governments still control the issuance of entry visas and, in the USSR, central authorities control access to foreign currency; still, the decentralization of exchange activities during the past year has been quite remarkable. Several American non-governmental institutions continue to administer a significant portion of the scientific exchanges, particularly the National Academy of Sciences and the Fulbright Program, but their historical dominance of nongovernmental exchange activities is rapidly diminishing.

SCIENTIFIC BENEFITS FROM EXCHANGES

Numerous testimonials document the scientific benefits of bilateral cooperation—to the East, to the West, and to the international scientific community. Hundreds of American and Soviet participants in exchanges have reported their experiences in a wide variety of scientific and technical journals and books, frequently as joint publications of Soviet and American authors. Also, they have written articles for the lay audiences in their countries, given public lectures, and made presentations at scientific conferences based

on their experiences as exchange scientists. Films of some exchanges have been adapted for television and movie audiences.

In the commercial arena, the best testimonials are advances in industrial and agricultural processes and products that can be traced in part to cooperative programs. Although there have been some examples of direct commercial benefits from cooperation in science and technology, to date the return for most American companies has not been commensurate with the investment of time by corporate leaders and scientists. For example, of the 400 senior executives who visited Moscow in the spring of 1988 in search of commercial opportunities, only a few can show concrete results from the visits, and the payoff from most of these undertakings is uncertain. Nevertheless, the American business community gives considerable importance to keeping abreast of developments in a country as large as the USSR. Cooperation in science and technology provides a good window for assessing the future commercial potential of dealings with the USSR.

The US Congress has conducted periodic hearings that have helped clarify the benefits and difficulties in cooperation with the USSR in science and technology. However, those who participate in these hearings find only one or two Congressmen in attendance and a light sprinkling of specialists from government agencies. Although many members of Congress are interested in Soviet-American relations and many are deeply involved in the development of the scientific base of the United States, few have given a combination of these two concerns high priority.

More than 25 reviews of different cooperative programs in science and technology have been carried out by US Government agencies during the past decade, but the distribution of these reviews has been very limited. Unfortunately, many key policy officials have their minds made up concerning the costs and benefits of exchanges, and they don't want to take the time to seriously examine the record. In most reviews, the conclusion has been that there can be important scientific benefits to the United States as well as to the USSR from carefully designed and well-managed exchange programs.

The US Government agencies that arrange cooperative programs prepare extensive budget justifications for their activities. They cite US reliance on the Soviet-designed Tokamak device in the development of fusion research in the United States. They point out the many lessons learned from Soviet space probes of the planets. They note the contributions of Soviet glaciologists to improved understanding of the environments at both the North and South Poles. They also caution about the pitfalls in cooperation and identify areas in which cooperation has not paid off, such as in the development of photovoltaic cells for solar power. Overall, the international affairs officers in the agencies believe that cooperation with the USSR is quite useful. Every trip to the USSR provides unexpected insights, and maintaining close contacts with a large county of surprises is very important to them. Although American scientists may not always gain new technical knowledge that can be applied today, they should be ready to take advantage of new Soviet approaches of the future.

Examples of cooperative activities that have been very beneficial to American working scientists can be seen in almost every important American scientific journal. A Soviet visitor to Harvard contributed to the scientific research that led to a Nobel Prize for an American specialist in DNA sequencing. Soviet mathematicians in Leningrad helped a visiting American from Purdue solve an important mathematical theorem that had eluded mathematicians for 30 years. An American visitor to Soviet freshwater fishery laboratories gained knowledge that was helpful in restocking Wisconsin lakes. And the list goes on.

It is often difficult to attribute specific scientific advances to a particular time period in a scientist's career. Advances usually result from an accumulation of knowledge and experience. International exchanges simply add a new dimension to the educational process. They may suggest new research methodologies

or discredit old ones. The may provide new data that support or contradict existing data. They may uncover new scientific uncertainties that require attention. In any event, in a significant number of cases, the exchange activities of American and Soviet scientists certainly accelerated the timetables for opening new scientific horizons.

THE FUTURE OF SCIENTIFIC EXCHANGES

In short, both countries have very large pools of highly trained specialists working in almost every field of science. Many of their activities overlap; their approaches may be similar or different; and their conclusions may be complementary or contradictory. The scope of science is too vast and the resources of science too limited not to encourage the broadest sharing of ideas and experience. Although the practical problems of carrying out cooperative programs are still formidable, the rewards can be substantial.

The scientific importance of long-term Soviet-American cooperation on global problems and the future payoffs from friendships established by young scientists early in their careers are only now receiving greater recognition in both countries. However, the short-term gains and losses will undoubtedly remain the dominant factor in political decisions of the two governments on specific exchange activities. Two of the most vexing issues confronting scientific exchanges in the immediate future are US policies on technology transfer and Soviet policies on access for exchange scientists to facilities located in closed areas. Greater accommodation of the legitimate interests of scientists when addressing these issues on a case-by-case basis would be a significant step forward in enriching the value of exchange programs.

Finally, as previously suggested, effective scientific exchange programs often require many years to develop and mature before significant benefits can be reaped. In the United States, only the US Government has the financial resources to support such long-term endeavors. Although private foundations are currently playing a major role in responding to new opportunities for exchanges under glasnost, these foundations are seldom inclined to support programs of scientific cooperation for many years. Therefore, the Bush Administration should take steps to reverse the steady decline during the past few years in government funds available for Soviet-American scientific cooperation. By foregoing the purchase of one jet fighter every three years, we could double the current size of our scientific exchanges.

OPPORTUNITIES FOR US-USSR COOPERATION IN THE INVESTIGATION OF ARCTIC STRATOSPHERIC OZONE

by

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ABSTRACT

The model of the polar atmosphere that has been developed to account for the Antarctic ozone hole is described, and the northern polar region is shown to be equally vulnerable to episodes of significant ozone depletion, if only very small changes were to occur in Arctic weather patterns. *In situ* investigation of the stratosphere north of the Arctic circle was the focus of several major campaigns conducted in early 1989. The results of these efforts are recounted briefly, with emphasis on the CNES stratospheric balloon campaign at Esrange in January 1989, an expedition which provided observations of the initial phase of an ozone hole. Northern polar atmospheric circulation patterns are shown to behave such that ozone hole formation was terminated at an early stage in 1989. However, the point is made that conditions in the northern stratosphere are perilously close to creating an Arctic ozone hole as large as any observed in the southern hemisphere. The result could be an ecological disaster north of latitude 65°, with the greatest probable threat to Scandinavia and the USSR. Possible cooperative research programs with the USSR to investigate relevant aspects of the polar stratosphere are discussed.

INTRODUCTION

The earth's stratospheric ozone layer has become a matter of increasing concern over the past decade. The discovery of significant ozone depletion above Antarctica during the austral springtime (Farman *et al.*, 1985) and its subsequent confirmation with satellite observations (Stolarski *et al.*, 1986), raised the question of whether the global abundance of stratospheric ozone would also decline. The release of chloroflourocarbons (CFC's) into the atmosphere had been predicted to cause depletion of stratospheric ozone (Molina and Rowland, 1974), but the pattern of the Antarctic observations did not correspond to the predictions of existing models. In the wake of intense research activity, a model involving heterogeneous chemistry, has emerged (Crutzen and Arnold, 1986; McElroy *et al.*, 1986; Solomon *et al.*, 1986; Rowland, 1988). According to this model, widespread and intensive stratospheric ozone depletion had occurred above Antarctica not only because the release of chlorine from CFC's had increased but also because of the presence of polar stratospheric clouds (PSC's) in that region. Ice crystals in the PSC's provide heterogeneous reaction sites for the release of chlorine (Cl) in a gaseous state into the stratosphere, at the same time removing gaseous nitrogen compounds (thus eliminating the possibility of forming reservoir compounds, such as $ClONO_2$, which significantly slow the reaction rate of chlorine with ozone). The gaseous Cl released from the dormant reservoir compounds, HCl and $ClONO_2$, reacts rapidly with ozone to form ClO, and concentrations of ClO are observed to increase during the course of the winter. The absence of other species with which ClO can interact allows ClO to interact with itself to form the ClO

dimer, Cl_2O_2. When sunlight returns to the polar region during austral springtime, solar radiation at near-ultraviolet wavelengths photodissociates Cl from the ClO dimer, thus providing a catalytic pathway for ozone destruction. The requirement of direct solar radiation for rapid ozone destruction ($\sim$ 1% per day) to proceed explains the seasonal aspect of the Antarctic ozone hole. The stratosphere is prepared during the extreme cold of polar winter by heterogeneous chemistry involving PSC's, causing denitrification and a build-up of ClO, but the ozone depletion process must wait until austral springtime when solar radiation levels are sufficient to complete the Cl catalytic cycle.

To gain better understanding of the processes that control the depletion of polar stratospheric ozone, attention has turned to the Arctic, the other region cold enough to sustain PSC formation. Several major campaigns to study the stratospheric chemistry of the Arctic have been conducted since 1987. Among several major efforts in this regard, the French space research agency, CNES, has conducted balloon campaigns at Esrange (northern Sweden) in January 1988 and January 1989. The results of this latter expedition are presented below.

THE ARCTIC STRATOSPHERE IN EARLY 1989

Balloon flights were conducted by the CNES at Esrange, near Kiruna, Sweden (68°N, 20°E), on January 23 and 30, 1989, to investigate the atmosphere to an altitude of 30 km. During this period, PSC's were observed from the ground above northern Sweden, indicating that conditions similar to those in Antarctica were present. The balloon observations revealed depletions in the ozone profile at high altitudes (Hofmann *et al.*, 1989; Sheldon *et al.*, 1989), very closely approximating the initial stage of ozone depletion in Antarctica (Hofmann *et al.*, 1987), which begins with modest decreases in the ozone mixing ratio at high altitudes and moves to lower altitudes and deepens in intensity as the season progresses. The January 1989 balloon observations also showed a total ozone column about 20% smaller than expected for the latitude of Esrange at that time of year.

Measurements by aircraft operating from Stavanger, Norway, revealed conditions in the Arctic stratosphere in late winter 1989 that were nearly the same as those observed in Antarctica during the same season (Palca and Lloyd, 1989). PSC's were observed, along with elevated levels of ClO, indicating that the same heterogeneous chemical processes believed responsible for preparing the Antarctic stratosphere for the development of the ozone hole were also in progress in the Arctic at that time.

During this same period, balloon measurements of the ozone profile were also made at a much higher Arctic latitude at the Canadian base, Alert, 82.6°N (Poulin and Evans, 1989; Evans, 1989). Those observations also showed decreases in high-altitude ozone from late January through mid-February, 1989, very similar to those measured by detectors on the CNES balloons.

Many similarities between the stratosphere in the two polar regions were revealed by investigations during early 1989. However, there is one important difference that appears to have precluded (thus far) the formation of a significant ozone hole at high northern latitudes: the Arctic polar vortex typically does not remain intact until the time of equinox, whereas the Antarctic vortex usually maintains its structure until well past equinox and consequently prevents stratospheric air from lower latitudes from mixing with polar air until the region has been fully illuminated for a few weeks. This difference in the atmospheric circulation pattern near equinox appears to be the principal reason for which a significant episode of Arctic ozone depletion did not develop in 1989.

The Arctic stratosphere had been preconditioned by passage through regions of PSC's, such that concentrations of gaseous odd-nitrogen compounds had been lowered and there had been a buildup of ClO, and the phenomenon had progressed to the point that ozone depletion starting at high altitudes near the Arctic Circle had begun. However, in mid-February, before depletion levels could become significant, the pattern of polar atmospheric circulation was disrupted and became turbulent; stratospheric polar air was replaced by, and mixed with, air from mid-latitudes. When the polar stratosphere no longer contained elevated levels of ClO, the ozone depletion process in the Arctic was at an end for early 1989.

Prior to January 23, the Arctic polar vortex had been centered near the north pole with streamlines in the stratosphere nearly concentric with parallels of latitude. At about that time, the Aleutian high-pressure system began to intensify and the center of the vortex shifted towards Scandinavia (Hofmann *et al.*, 1989). This displacement of the vortex from the geographic pole led to its break-up in mid-February 1989 and the termination of polar ozone depletion for that season.

ARCTIC OZONE IN THE FUTURE

From the preceding discussion, it would appear that the Arctic stratosphere in future years will be preconditioned for ozone destruction (i.e., large concentrations of ClO will build up during the winter), if stratospheric temperatures fall to low enough values to allow significant PSC formation. PSC's tend to remain fixed in geographical location by orographic features or tropospheric high-pressure cells. Stratospheric air is then processed by "flowing through" the region of the PSC (Douglas and Stolarski, 1989); a PSC coverage of ~10% appears to be sufficient to "process" the entire polar stratosphere in only a few days. So the failure of the polar vortex "containment vessel" was the key to the aborted attempt to form an Arctic ozone hole in 1989. Thus, an attempt to predict the future in the Arctic in this regard appears to involve three questions: (1) Will the concentrations of Cl in the stratosphere remain at a high level? (2) What are the future prospects for PSC formation? and (3) What is the likelihood that the Arctic polar vortex will remain intact until equinox? These three questions deal with the principal factors that lead to the development of a polar ozone hole: Cl, PSC's, and the vortex.

The first question can be answered unambiguously in the affirmative. The use of CFC's continues at a rate that assures high concentrations of Cl in the stratosphere in the foreseeable future. Even if the manufacture of CFC's were to stop immediately (a most unlikely prospect), the present abundance of CFC's in the lower atmosphere would continue to leak into the stratosphere, keeping Cl levels there at uncomfortably high levels for many years in the future.

The second question asks whether temperatures in the Arctic stratosphere will be cold in the future, as was the case in 1989. Of course, this question cannot be answered with confidence. In 1989 the lowest temperatures on record in the Arctic stratosphere were observed. At the same time, temperatures at ground level were at record high values. At Rovaniemi, Finland, a city located on the Arctic Circle, on January 27, 1989, we observed PSC's overhead, while the ground-level temperature was above freezing; there was actually water standing in the city gutters! This observation provides anecdotal confirmation of the suggestion by Shine (1988) linking higher tropospheric temperatures to lower temperatures in the stratosphere through greenhouse warming of the lower atmosphere and greenhouse deprivation of the heat budget to the upper atmosphere. Thus, as greenhouse warming progresses it seems reasonable to expect Arctic PSC's in future years on a regular basis during the winter, rather than as rare events.

The question of the Arctic polar vortex is more uncertain. Destabilization of the Arctic circulation pattern through intensification of the Aleutian high-pressure system, as in early 1989, is a typical late winter development. Perhaps this turn of events will continue in the future and the development of a significant Arctic ozone hole will be averted by this means. However, the early 1989 observations suggest that another course of events is possible that could lead to ozone destruction in the northern hemisphere as severe as that in Antarctica. The high-altitude ozone depletion measured at Alert (Poulin and Evans, 1989; Evans, 1989) indicates that the air parcels under observation had been processed through PSC's and subsequently transported south to a low enough latitude for solar radiation to drive the Cl catalytic cycle; then the circumpolar circulation pattern brought the ozone-poor air back north to the 82.6° latitude of Alert. It is clear that the Cl catalytic cycle cannot have been a local phenomenon at Alert in January because polar night had not yet ended there when high-altitude ozone depletion was observed.

Although activity of the Aleutian high-pressure system terminated the ozone depletion process in 1989, it appears that another scenario is possible. Instead of pushing the vortex so far from the pole that turbulence sets in and break-up occurs, if the polar circulation pattern were displaced only slightly from the pole, consider what might happen. An intact, but displaced, vortex could provide a pathway whereby stratospheric air would be processed in cold, high-latitude regions where PSC's abound and then spend another part of their circumpolar traversal at lower latitudes where the Cl catalytic cycle would deplete ozone rapidly. This prospect is not at all pleasant: in principal, Arctic ozone destruction could begin earlier in the season, as was the case in 1989. The initial stages of polar ozone depletion were observed in the Arctic two months before equinox (Hofmann *et al.*, 1989), whereas in Antarctica similar observations were not made until one month prior to equinox (Hofmann *et al.*, 1987). Also, it is possible that a displaced polar vortex could prolong stratospheric processing later in the season with PSC's at high latitudes continuing to process stratospheric air parcels that spend most of their lifetimes in sunlight at lower latitudes. Assuming that displacement of the Arctic polar vortex would be driven by an Aleutian high pressure system, the regions most likely to feel the effects of a reduced ozone layer are northern Scandinavia and the northwestern portion of the USSR.

The worst-case scenario presented above for Arctic ozone destruction would bring another north-south hemispheric difference into sharp focus, that of population and economic base. In the northern hemisphere, a substantial population lives at latitudes above 65°, and forests and other agricultural resources there constitute an enormous resource that would be threatened. Similar circumstances do not exist in the southern high-latitude region.

ARCTIC-STRATOSPHERE RESEARCH PROGRAMS

Although a great deal of understanding of polar ozone depletion has been gained during the past few years, it is also clear that more remains to be learned. The special circumstances in the Arctic that have been described deserve special attention. It seems that the investigation of stratospheric chemistry in the Arctic cannot be done thoroughly without measurements from detectors on long-duration balloons. The results of investigations in early 1989 indicate that Arctic stratospheric air parcels traversed a wide range of latitudes during January-February 1989. *In situ* observations aboard long-duration balloons would allow this point to be investigated objectively and would define the latitude regime where various chemical processes dominate.

In situ investigation of the Arctic stratosphere will require the cooperation of Arctic nations, the US and the USSR, as well as Canada and the countries of Scandinavia. At the present time stratospheric

balloon investigations that originate in Scandinavia must also terminate there. However, there have been balloon campaigns from Esrange in the past in which the payloads were launched at Esrange and impacted in the USSR. These campaigns involved investigators from the USSR and indicate that such cooperative programs are possible. The need for increased understanding of the Arctic stratosphere should provide sufficient motivation for all Arctic nations to relax existing barriers to research activities. This urgent research requirement should also be seen as another opportunity for cooperation between the US and the USSR in the investigation of this potential threat to the global environment.

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NUCLEAR POWER AND EAST-WEST EUROPEAN COOPERATION

by

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INTRODUCTION

Nuclear energy development in all of Europe, East and West, has been adversely affected by the Chernobyl accident of 1986, which provoked new concern about the safety of nuclear power plants. Parallel to their efforts to improve the safety of the present generation of nuclear reactors, European countries are now also exploring new technological solutions for their future nuclear power.

In the past, nuclear power in Eastern Europe developed within the framework of COMECON, under the leadership of the Soviet Union, while in Western Europe it has developed on a national basis. Interaction between Eastern and Western European nuclear programs has been negligible.

In the future, however, growing international cooperation will probably affect European nuclear power as well as other areas; the programs of Western European countries will be less marked by nationalism, and there will be closer ties among Eastern and Western European countries.

These topics will be discussed in this paper under four main headings: nuclear power developments in Eastern and Western Europe; prospects for international cooperation in Europe; prospects for future nuclear power; prospects for cooperation among Eastern and Western European countries.

NUCLEAR POWER DEVELOPMENTS IN EASTERN AND WESTERN EUROPE

A substantial difference exists between Eastern and Western Europe in the organizational and industrial structures of nuclear power.

The direction and scale of nuclear power programs in East European countries has always been determined by the dominance of the Soviet Union. Ever since the beginning of nuclear power in the 1950s, the Soviet Union has conceived its nuclear program on a multinational basis with full integration of all its allies.[1] This policy was pursued with varying degrees of success in the 1970s and was fully updated in the 1980s. A major milestone came in December 1985, when the "Comprehensive Program of Scientific and Technological Progress of CMEA member countries to the Year 2000" was approved. In this program, nuclear power is one of five directions for further technological development. The CMEA countries envisage a plan to refine and further construct atomic power plants having the VVER-440 and VVER-1000 water moderated reactors (the Eastern version of the pressurized water reactor) with enhanced technological and economic efficiency, a high degree of standardization and unification of equipment, and qualitatively

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new, highly dependable systems for control and automation of manufacturing methods.[2] Waste disposal, nuclear power district-heating with conveyance of heat over long distances, as well as the development of equipment for fast-breeder reactors, are also part of this Soviet-East European effort.

Implementation of the CMEA countries' program is based on a network of mutual dependence between the Soviet Union and Eastern Europe, with integration and specialized agreements designed to deepen socialist economic coordination in the nuclear sector through the 1990s. Through these agreements the Soviet Union controls the division of labor among East European countries, the design and standardization of nuclear equipment, the advanced training of scientists and other specialists, the export of nuclear technologies, the dissemination of technical information, and a myriad of other activities. So far, the East European nations have been unable to develop independent nuclear programs, and they are required to obtain enriched uranium for their reactors from the Soviet Union and to return spent fuel for reprocessing.

In the West European countries, on the other hand, nuclear power programs have evolved on a strongly competitive national basis. The European Atomic Energy Community (EURATOM) established in the late 1950s for the common development of nuclear power, had a major role at the beginning for European nuclear R&D, but was not involved with the industrial application of nuclear power because of national competition and military implications. Each country has followed its own approach and has set up its own nuclear programs, with differing degrees of success. Nonetheless, the most common nuclear reactor in West European countries are the types of 1000-1300 MW pressurized water reactors and boiling water reactors, built under license from U.S. firms or with technology developed in countries such as France and West Germany.

However, West European countries have successfully joined their economic and industrial efforts to develop fast-breeder reactors and to do scientific research on nuclear fusion. The long-term commercial future of these technologies, as well as their initiation in a period of more advanced integration of Western European economies, has made cooperative ventures more possible and successful. Cooperative initiatives in the development and construction of the present light water reactors have mostly been limited to the areas of nuclear safety, the fuel cycle, and waste disposal. No integration or specialization in the construction of nuclear power plants in Western Europe has ever been seriously attempted. However, a certain degree of integration is now becoming apparent, making more likely the prospects for less nationalism in future nuclear power in Western Europe for reasons that will be discussed below.

The degree of nuclear power development in Europe today varies widely from country to country and from East to West. While some countries, such as France, are highly developed in nuclear energy, others have not yet embarked on, or are opposed to, its development. The number of reactors connected to the grid, installed capacity and the share of electricity supplied by nuclear power as of December 1987 are shown in Table 1.[3] Rumania and Poland, which started building their first nuclear plants in 1983 (Rumania, five 600 MW reactors of the Canadian Candu design and, Poland four VVER 440 MW reactors) are not included. Denmark, Norway, Luxembourg, Greece, Ireland, and Portugal have not yet decided upon or started nuclear programs. Austria renounced the use of nuclear power and did not start up its only plant. Italy abandoned their present-day nuclear technologies of producing electricity after Chernobyl. The table also shows the net difference between Eastern and Western Europe as a whole in the development of nuclear power.

As of December 1987, nuclear plants in Western Europe contributed 33.0% of their electricity supplies, a share twice that of the world average (16.6%) and greater than that of the United States (17.7%), Japan (27.1%), and the Eastern bloc (11.3%). About 10,000 MW were installed in the six East European countries

and, at that time, 33 000 in the Soviet Union, the the total being less than half the approximately 108 000 MW installed in Western Europe (the total in Europe being 150 000).

Eastern and Western Europe show significant similarity in the type of reactor adopted, the pressurized water reactor (PWR) dominates both regions. As of December 1987, 47 VVER type reactors were operating and 41 were under construction in the Eastern bloc, while 81 PWR were operating and 14 were being built in Western Europe. Before the Chernobyl accident, European nuclear power programs were envisaging greater use of this type of reactor: about 180 plants of this type were scheduled to operate in Europe by the year 2000, 120 of them in Western Europe. What impact has the Chernobyl accident had on these plans, and what are the prospects for future development of nuclear power in Europe?

In Eastern Europe, government commitment to nuclear energy was strongly reaffirmed after Chernobyl. In the 42nd session of the CMEA countries, held in Bucharest in November 1986, the Soviet Union and the other member countries declared their determination to pursue vigorously their programs for the construction of nuclear power and heat supply stations to the year 2000 and attached great importance to developing cooperation among the nuclear power industries of the member states. By the year 2000, the European members of the CMEA (excluding the USSR) were aiming to attain an installed nuclear capacity of 50 000 MW versus 8000 MW in 1986.[4] Nuclear power was expected to generate between 30 and 40 percent of the total electricity being produced, compared with about 10 percent at present. It is difficult to imagine that this commitment will be met.

In Eastern Europe, doubts and some opposition to nuclear power arose after the Chernobyl accident, even if to a smaller extent than in Western Europe. Poland, for example, halted construction of its first nuclear plant at Zarnowiec for several months. Concerns about nuclear power have been publicly voiced in East Germany, Romania, and Czechoslovakia. These reactions did not dent the resolve of the CMEA countries to press ahead with their nuclear power programs at that time, but their earlier attitude toward nuclear power seems recently to be profoundly changing.

Public concern about nuclear power, and Western style debates over the safety and environmental implications of nuclear expansion, now have new prominence in almost all Eastern countries, and—unpredictably—especially in the USSR. Antinuclear sentiment, furthered by the new Soviet policy of openness, is also stimulating broad ecological interests, often as part of wider political problems, such as, general political dissatisfaction, nationalism, local feelings, etc.

In the USSR, public opposition to the expansion of the Soviet energy program began to be important during 1987 and has grown significantly in recent months, posing a serious threat to the country's ambitious energy programs. In contrast to earlier protests, the campaigns held in the fall of 1988 were massive in scale, involving thousands of people. Although it is difficult to judge the effect of this mounting popular pressure on the reshaping of Soviet energy policy, Moscow has renounced several nuclear power plants already in operation or under construction in the last two years.[5] According to a senior official at the Ministry of Atomic Energy, total Soviet nuclear capacity in 1990 would at best reach 45 000 MW—less than two-thirds the amount forecast by economic planners before Chernobyl.[6]

The nuclear power issues, initially debated mainly in the Ukraine region, where the Chernobyl accident took place and 40 percent of the USSR's nuclear capacity is located,[7] are now showing new facets. There are alarming revelations about other nuclear disasters in the USSR, such as the nuclear accident at a military complex in the Soviet Urals in 1957, when an explosion released large amounts of radioactive material, requiring the evacuation of thousands of local residents,[8] and protests that prevented a Soviet nuclear ship from entering four ports in the Soviet Far East.[9] According to Yevgeny Velikhov, vice president of the

USSR Academy of Sciences, nuclear power will turn out to be the biggest issue for the new Supreme Soviet.[10]

It is difficult to predict the effect of this growing antinuclear sentiment in the Soviet Union on the Eastern bloc nuclear programs.

The favorable official posture held prior to Chernobyl prevented Eastern European countries from being prepared for the possibility of serious accident. Now, new concern about safety may make it necessary to adopt costly new technical solutions, such as reactor containments, which in turn might strongly affect both their present and future nuclear plans.

Public concern about nuclear safety has also appeared in the six Eastern European countries, though not on the scale now existing in the Soviet Union. For example, in August 1987 the Polish Minister for Environmental Protection and Natural Resources, Stefan Jarzebski, said that in the interest of safety he was personally happy with the slower pace of construction work at the Zarnowiec nuclear plant.[11] In 1988, Hungarian authorities retreated from plans to permit construction of a low- and medium-level waste disposal facility because of local opposition.[12]

In December 1988, Yugoslavia's Federal Assembly enacted a moratorium on the construction of nuclear power plants until the end of the century.[13]

Unlike Eastern Europe, the reaction of the public in Western Europe against the continuation of nuclear programs has been strong since right after the Chernobyl accident. Although most governments have reaffirmed the continuation of their national nuclear power programs, anti-nuclear feelings have increased in nearly all Western European countries, with rare exceptions, such as France. Opinion polls in Western Europe have shown between 50% and 80% of the public opposed to any expansion of nuclear power. The deterioration of public sentiment toward nuclear power has put West European nuclear institutions and industry on the defensive, and in a number of countries the broader question of the existence of any nuclear power at all was and is being largely debated. Austria and Denmark have renounced nuclear power. In Sweden, a national referendum held in 1980 on nuclear power led the Congress to decide in 1985 to phase out the twelve installed nuclear power plants by the year 2010. A first reactor is to be closed down in 1995 and a second in 1996. The Netherlands and Finland have postponed decisions to order nuclear plants. Italy has become the first European country to declare a moratorium on the construction of nuclear power stations based on current nuclear technologies, and to commit itself to the development of future nuclear power.

Reduction or cancellation of several national nuclear programs came when nuclear power plant construction was already slowing down in Western Europe, continuing a trend that had begun even before Chernobyl. This slowdown was due to a number of factors: saturation of electric capacity, a growing interest in coal-fired stations, and political decisions to limit the share of nuclear energy (or to phase it out entirely).

Chernobyl undoubtedly reinforced this trend, accelerating the end of a nuclear power development cycle in Western Europe. Although about 16,000 MW went into operation (13,000 MW in France) in 1986-1987, few nuclear power units are expected to be ordered by the year 2000. For example, France has reduced the pace of nuclear power orders from two units per year in 1983 to 1 unit every four years starting in 1987.[14] Belgium officially halted its own nuclear power program in December 1988, renouncing the construction of a planned eight nuclear power units. This confirms the virtual full stop of nuclear power plant construction in Western Europe, at least until the end of the century.[15]

PROSPECTS FOR INTERNATIONAL COOPERATION IN EUROPE

The Chernobyl accident demonstrated the intrinsic continental nature of nuclear power and stimulated different reactions in the European states in relation to their nuclear interests. Although several less advanced countries have renounced nuclear power in the short term, it appears it would be very difficult for them to avoid its development in the long run.

What does seem clear now is that all European countries—those presently less committed, and having little or no nuclear power, as well as those more advanced, with large installed nuclear power capacity—will be working for future nuclear power and that this will inevitably be accomplished with new, perforce transnational, approaches.

In fact, nuclear power has already entered a new phase in Europe's energy infrastructure. This is hardly a unique situation. In the past, the emergence of new energy technologies often changed energy infrastructure. For instance, many small hydroelectric plants were closed when larger dams and electric grids were built. It seems that a similar process is starting to take place in Europe between nuclear power and other forms of energy production but on a larger, broader scale. It makes no economic sense to transport fossil fuel in one place to produce electricity that will be transported to other distant areas afterwards. It does, however, make sense to do this with nuclear fuels. Over the next century nuclear technology could make it possible to develop single nuclear energy units to supply increasingly larger territories, using advanced electric transmission lines or producing synthetic fuels to be piped over long distances.[16]

As we have seen, in Europe nuclear energy has already been developed in the countries that have the most favorable natural and industrial conditions: large rivers, unpopulated coasts, stable geological areas, and impressive technological and organizational capabilities. Surplus electricity now produced in these more advanced countries is exported to neighboring countries.

In March 1987, France contracted with the leading Swiss power supplier to provide it with electricity starting in 1994. The Swiss company will contribute the cost of 200 MW. The contract is not tied to the construction of any particular power station, and the agreement covers both fixed and variable operating costs.[17] France provides Britain with power equivalent to the output of two nuclear power stations. Under plans now being considered by Electricit de France (EDF), any British company wishing to secure imports would be given the opportunity to invest in a French power station, thereby extending a cross-border "power-for-money" scheme already adopted with the Swiss.[18] France now exports about 10% of its electricity production.[19]

These examples show that it may be simpler, at least in the near future, to build additional plants in countries with large and experienced nuclear programs than to scatter them in countries with less developed or developing nuclear programs.

In countries with a weak commitment to nuclear power, attempts by pro-nuclear political forces to bring about a fast recovery in public confidence seem to have failed for now. For the less developed countries, the nuclear option could be more viable in the framework of an integrated European nuclear system—either by importing nuclear power from other states or by building nuclear plants in close collaboration with other states—than as a purely national solution.

An integrated European nuclear system will certainly be further promoted in Western Europe by the creation of the West European Single Market of 1992, more particularly the envisaged single European energy market. As a result "common carrier" principle—that is, the possibility for European utilities carrying the electricity they produce on other grids—is under consideration.[20]

The concept of such an integrated system will obviously also involve profound changes in the relations among West European national institutions, electric power industries, and nuclear supply industries; these are already under way.

The most striking example concerns the nuclear supply industries. Until 1988 the Western European energy industry was characterized by the presence of several national companies of different size and strengths. This situation is now quickly changing under the pressure of three main factors: 1) world overcapacity in engineering and production of electromechanical equipment; 2) competition on world markets, which requires companies to be larger and stronger; and 3) the general wave of European industrial and commercial mergers resulting from the idea of the Single Market of 1992.

Alhough these changes do not always directly impact the nuclear industry, they are modifying domestic power industries so profoundly that it is no longer possible to believe that nuclear power can be developed on a national basis in the next century in Western Europe.

A first step toward this restructuring was taken by the Swedish ASEA-Atom and the Swiss Brown Boveri in January 1988, when the two companies merged to form the world's largest heavy electrical-engineering group: ASEA-Brown-Boveri (ABB).[21]

In December 1988, the second largest electromechanical group was announced by the French Compagnie Generale d'Electricite (CGE), and the British General Electric Company (GEC), which agreed to merge CGE's Alsthom and GEC's Power Systems Group, most of whose business is power generation and transmission. This new venture can provide, for example, the conventional-side equipment for British and French nuclear power plants.[22]

New steps toward further rationalization of the energy industry sector in Europe were taken in January 1989, when the Swiss-Swedish ABB group and the Italian FINMECCANICA also agreed to merge many of their energy-related activities.[23]

A last important merger, which has led to the formation of a third large energy-industry pole in Europe, was effected by the French Framatome and the West German Kraftwerk Union (KWU) of Siemens, both vendors of power plants, nuclear included. These companies have been discussing for some time the feasibility of forming a consortium for joint design and construction of a 600 MW-PWR in Indonesia, since that government asked them to submit a joint project in 1987.[24] Talks intensified at the beginning of 1989, and an agreement was signed in mid-April, when Framatome and KWU decided to pool their international activities in the nuclear pressurized field in a joint subsidiary called Nuclear Power International.[25] According to a French official, a rapprochement between the German and French vendors could herald a necessary rationalization of the European nuclear industry and should ideally be "one element of a broader pole" of European nuclear rapprochement involving areas such as safety, R&D, and the fuel cycle.[26] Cooperation between France and West Germany on reprocessing was announced June 6, 1989, as a part of this broad nuclear cooperation.[27] France's aim during its chairmanship of the European Communities, to start in July 1989, is to stimulate special attention to the "removal of national restrictions on the free sale of energy across borders, harmonizing indirect taxation rates, and creating a common distribution network for gas and electricity" in order to "speed up development of a single market for energy".[28]

Other industrial alliances around the above mentioned three Western European energy industry poles are growing, involving firms from all over the world.

Three examples, closely related to the future development of nuclear power in Europe, are worth emphasizing. In October 1988, the Kraftwerk Union (KWU) division of Siemens and Asea Brown Boveri

(ABB) made public the decision to pool their resources for development and marketing in the field of high-temperature gas-cooled reactors (HTR). This joint venture was also fostered by the two companies' interest in cooperating in this field with the Soviet Union, as we shall discuss below.[29] In may 1989, ABB and Westinghouse agreed to join forces to supply nuclear services to the European market: another milestone in the ongoing and rapid concentration of the European nuclear/electromechnical supply industry.[30] The British U.K. Atomic Energy Authority and Rolls-Royce & Associates, and the U.S. Combustion Engineering and Stone & Webster Engineering, signed a Memorandum of Understanding to cooperate in designing a modular inherently safe advanced 300 MW pressurized water reactor.[31]

All this goes to show that initial changes with important long-term implications on future nuclear power development are in progress on the Western Europe energy scene. Industrial restructuring will inevitably be flanked by other processes aimed at developing new and closer links among national institutions and electric power utilities, in order to respond to the continentalization of the energy problems and to overcome narrow national approaches.

PROSPECTS FOR FUTURE NUCLEAR POWER

Technological, environmental and economic uncertainties cloud the future of energy production. Diversification of energy supplies (coal, gas, nuclear, oil, renewable) has up to now been the prevailing approach in coping with these uncertainties, making it possible to share the various risks associated with the use of any source of energy. This approach cannot be changed quickly. Only in the long run can we envisage most energy needs being satisfied by nuclear technology, in particular by nuclear fusion. At the moment, however, the growth of nuclear fission technology, which already makes a significant contribution to European energy requirements, is still affected worldwide by unpredictable problems and lack of experience.

At the same time, growing concerns over the use of fossil fuel and its impact on global warming—the so called "greenhouse effect"—is fostering worldwide reexamination of the nuclear energy option. Nuclear power is predicted to grow again, but at a faster pace than from the 1970s to the 1980s, significantly curtailing the fossil fuels emissions responsible for this effect.[32] Because of the long-term economic and environmental implications, further expansion of nuclear power has to be based on careful comparative assessment of the past use of all energy sources and of those expected to be used in coming years.

It should be stressed that European experience in the area of nuclear power is substantial and worthy of preservation. Nuclear technology can be thought of as an "artificial raw material" intrinsically strategic of Europe, especially because it lacks "natural energy raw materials". However, only the capability of all Europeans to carry out reliable and economic nuclear power programs will make this technology a credible resource.

One potentially promising step for the future of nuclear fission power well beyond Europe might be the development of "passively safe" nuclear reactors (sometimes also called "inherently safe" and, less technically, "walk away" or "forgiving" reactors) whose safety depends not on mechanical or human intervention, but rather on immutable physical principles that cannot be abrogated even in emergency situations. Among these principles are those of gravity and natural convection, which can be exploited in systems such as emergency core cooling and decay heat removal systems.

The prospects for developing passively safe nuclear reactors have been investigated since the mid-1980s,[33] not only because of their safety characteristics, but also for economic reasons. These reactors are expected to be simpler and smaller—therefore easier to design, build, and operate—than current nuclear

power plants. Most of their systems and components are envisaged to be highly standardized and suitable for shop fabrication, allowing reductions in construction time and cost.

Some experts identify two groups of reactors with passive, inherently safe characteristics: "evolutionary" reactors—considered not inherently safe in the strict sense of the term, but having some inherently safe features— that are developed from the present generation of nuclear reactors by reducing their size, enhancing their inherent characteristics, using fewer valves and pipes, and by simplification; and "revolutionary" reactors, based on innovative concepts and designs. Most of technical solutions for the first group have already been tested and should be commercially available around the year 2000. The second group requires more research and development, and will probably be available around the year 2010.

Proposals for a new generation of nuclear reactors were voiced on several occasions right after Chernobyl. The most significant call came from the Soviet leader Mikhail Gorbachev, who in a message to the United Nations Secretary-General stated, "The International Atomic Energy Agency could sponsor international efforts to develop a new generation of economical and reliable reactors with enhanced safety of operations compared to existing reactors."[34]

However, a new generation of nuclear fission reactors was cautiously being considered at that time. In particular, the international nuclear industry showed strong resistance to possible changes, especially technological changes that might be seen as an indirect complaint about the safety of current reactors, hampering construction of new reactors based on existing designs and possibly even threatening the operation of older plants.

This attitude was clearly reflected in a speech by the Director of the IAEA given during the summer of 1987. Highlighting the new significance attached to the possibility of a new generation of reactors, he observed that "There will be some who hold or wish that no such new generation of nuclear power plants will be born. I think they will be proven wrong. I think nuclear power will survive today and expand tomorrow, provided no accidents with release of radioctivity occur."[35]

At the International Scientific Forum on Fueling the 21st Century held in Moscow in October 1987, where East and West debated the "inherently safe" reactor concept, experts were strongly divided between those in favor of improving existing LWR's and those who wish a "revolutionary" approach to future nuclear power. The latter question whether existing reactor designs can be improved sufficiently to meet new safety goals.[36]

In 1988 and the first part of 1989, with most nuclear power programs halted or saturated until the next century, a second nuclear fission era gained new prospects, (barring the demonstrated feasibility of fusion or other "energies of the future"). Commitment to the development of future nuclear power was made or has been under examination by an increasing number of governments, national and international institutions, industries, research centers, etc. Some examples may be given here.

In Italy, the New Energy Plan approved by the government in August 1988, and now submitted to Parliament, calls for a concrete program of research and industrial development on reactors with enhanced passive and inherent safety. A committee has been set up to propose an action plan and explore the possibilities for international agreements to this end.[37]

In the United States, a bill proposing a national energy policy to reduce global warming indicates, among the various alternatives, a reexamination of the nuclear option to see if it is possible to develop a new generation of nuclear energy that is cost-effective and safe. The bill also addresses such concerns as waste disposal and proliferation. Without meeting these basic criteria, nuclear power is seen not to pass the critical test of public acceptability.[38]

As we have seen, British and American firms are exploring the development of a small integral reactor (SIR)—a 300 MW pressurized water reactor—in which new passive characteristics will be introduced. According to *The Independent*, new reactors are winning strong support in the United Kingdom.[39]

Other Western European firms such as Asea Brown Boveri and the West German Siemens are also increasing their commitment to study and develop new reactors. New reactor concepts and designs, such as the PIUS[40] and modular HTGR[41] reactors, have been presented and discussed in various forums. A modular HGTR reactor is also the object of cooperation between West Germany and the USSR, as we will see later. Siemens is also studying the development of a small boiling water reactor that uses passive safety features.[42]

In Japan, the University of Tokyo has proposed a generic reactor concept, the "inherently safe and economic reactor" (ISER), to be developed by an international association.[43]

The general aspects and surveys of future nuclear power have also been considered by international institutions such as the European Communities Commission and the International Atomic Energy Agency. The IAEA has created an international working group to discuss new types of reactors.[44]

In summary, although a consensus on future nuclear power, envisaged as more safe and economic, is to be found worldwide, disagreement about what the possible technological solutions are likely to be has not disappeared since Chernobyl.

As we have seen, proposals for new types of reactors put forward by national institutions, industries, universities, and research centers have been multiplying. But they still need to pass tests, the most important being public acceptance. This is widely reflected in the discussions held in various countries and in the international organizations. Some of the issues affecting the selection of reactors to be used over the next century are those involving technology, management, regulation, organization, public communication, international relations, and so forth.

In both Eastern and Western Europe, where proposals for "evolutionary" reactors (such as SIR or SBWR) and "revolutionary" (such as PIUS, or HTGR) are now under consideration, future nuclear power appears to taking shape within a framework of conflicting solutions, all far from becoming the prevailing solution for all European countries. In fact, because of their different experience and industrial capabilities in the area of nuclear power, as well as different energy uses and requirements, it seems reasonable to expect that countries will group their own interests and options around specific reactor concepts that allow them to exploit collectively their individual experience to date, to develop new reactors, and to provide an alternative to existing plants if necessary.

PROSPECTS FOR COOPERATION AMONG EASTERN AND WESTERN EUROPEAN COUNTRIES

Technological cooperation in nuclear power between Eastern and Western Europe has always been limited for three reasons: 1) the Soviet Union's predominant role in the development of nuclear energy in Eastern Europe; 2) COCOM limitations on high technology transfer from West to East; and 3) the lack of economic incentives.

As we have seen, the basis of nuclear power programs in the Eastern European countries has always been determined by the strong relationship between the Soviet Union and its allies, in which each has a specific role in the construction of nuclear plants. For example, Czechoslovakia has the greatest capacity for

manufacturing reactors and turbine systems; Bulgaria is involved mostly in the construction of equipment for electricity transmission and voltage regulators; Poland builds steam generators, valves and fittings; Hungary provides installations for the treatment of water from primary and secondary system pumps, automatic devices, and fuel-loading equipment. The Soviet Union, of course, has the predominant position, being the only country capable of producing heavy equipment and large reactors and of providing fuel cycle services (uranium enrichment and fuel reprocessing). The limited autonomy of the Eastern European countries in the construction of their nuclear plants has inevitably reduced their ability to deal with other countries.

The export controls on high technology equipment adopted by Western countries have also lessened nuclear cooperation between Eastern and Western Europe. Nuclear reactors are still included as a high-tech item on the restricted list of the U.S. Department of Commerce. Even in the relatively non-sensitive area of commercial power reactors, the U.S. have been controlling exports to prevent the transfer of light-water reactor technology, which might be of use to the Soviets in naval propulsion.[45]

Western European policies have been more liberal to Eastern countries in the nuclear field, but dependence on U.S. licenses and concern about security have prevented the finalization of a number of commercial and cooperative initiatives with the East. One of the best illustrations of this is the Kalingrad nuclear power plant project, launched in the mid-1970s by the Soviet Union and West Germany. The project was abandoned after objections were raised inside COCOM by the United States concerning Soviet refusal to allow on-site inspection of nuclear facilities (the Soviet Union now allows some on-site IAEA inspections) and the security implications associated with the transfer of nuclear technology to the Soviets.[46]

Cooperation in the nuclear sector has also been limited by economic factors. The Soviet Union has never shown substantial interest in obtaining nuclear technology through cooperation with any Western country. Instead it has sought to be technologically independent. By including Eastern Europe in its market for nuclear technologies, the Soviet Union aimed at achieving otherwise unrealizable economies of scale for the production of nuclear reactors. The presence of Western industry in Eastern European countries would have undermined this scope. Lack of financial resources has been another constraint in limiting the flow of Western technology to Eastern European countries. For example, financing of the construction of the Rumania's Cernovada plant, which operates with Canadian reactors, has been partly solved through a counter-trade program.[47]

However, these factors limiting cooperation between Eastern and Western Europe did not prevent several countries from exploring and initiating cooperative ventures. For example, in 1964-1965 Czechoslovakia made inquiries in Great Britain and France about the possibilities of purchasing a heavy-water reactor because the Soviet Union had refused to help complete a reactor of this type. Rumania, desiring a degree of independence from the Soviet Union, also sought assistance in developing nuclear power from several Western countries, including Britain, Canada and Sweden. None of these initiatives succeeded at the time, largely because the United States, for security reasons, prevented the export of most of the necessary equipment. A decade later Rumania signed an agreement with Canada to buy a CANDU reactor. Presently, five reactors of this type are under construction.

Among past cooperative ventures in the nuclear sector between East and West Europe, the Finnish experience is an instructive example and shows how nuclear technologies developed on both sides can be integrated. In 1970 Finland signed agreements with the Soviet Union for two VVER-440 reactors; this agreement included modifications in the Soviet reactor design that required collaboration between the Soviet Union and several West European countries. West Germany, Great Britain, and Switzerland provided the Finns with several systems and components designed in accordance with Western safety criteria.[48]

Since the 1960s, East European nuclear agencies have also signed agreements for cooperation with their West European counterparts. In general, these agreeements are centered on minor or highly specific applications of nuclear technology and are mostly limited to the exchange of scientific and technical information, for example on applications in agriculture and medicine. Although the results in most cases were more symbolic than practical, the accords can be considered an important institutional framework, which, in several cases, has already been employed in revitalizing cooperation.

This brief review of East-West cooperation in the nuclear sector shows that mutual interests have existed in the past and should prompt European countries to combine their different experience and resources in the future. This prospect is enhanced by the Chernobyl accident's impact on the development of nuclear energy programs in both the East and the West. Economically and technically, the Chernobyl accident could be seen as a turning point in the development of nuclear fission energy in Europe. After Chernobyl it is no longer possible to ignore what is going on in the nuclear power plants of a neighboring country.

East and West European countries experienced the same threat of contamination by radioactive fallout produced by a reactor disaster that occurred far from their lands. This threat revived the debate over the risks of nuclear power, and affected the prospects for existing and planned nuclear reactors. In particular, a new variable has been introduced into the nuclear power decision-making process. Even a country that renounces the use of nuclear power in its own territory is obviously still exposed to the dangers of a nuclear accident in a distant state.

For the first time, some governments—but only of states that have no nuclear power—began to take directly antinuclear stands in international meetings.[49] In Europe, this attitude may have significant implications for relations among countries, in either the East or the West.

In fact, East and West have different approaches to nuclear safety. In the East, for example, containment systems of the type used in Western Europe to control radioactive material escape to the environment in case of meltdown were introduced only recently. A nuclear accident in a pressurized water reactor (the most common type in all of Europe) would therefore be likely to have more repercussions after Chernobyl.

Before the Chernobyl accident, the differences between nuclear power programs in Eastern and Western Europe did not cause serious concern. Debates were mainly nationally focused and confined to each side. Even the Three Mile Island accident justified this approach. The accident, even if large, affected only the plant.

In the case of Chernobyl, the entire population of Europe was endangered. The isolation of nations in European nuclear development can no longer be acceptable since Chernobyl demonstrated the common fate of the continent in the case of a large nuclear accident.

In Europe, one of the first focuses of cooperation must be the management of existing plants. After all, the plants already built represent a reality commonly shared by all Europeans, and this may force them to work together. As we have seen, about 150,000 MW in nuclear plants (including 33,000 in the Soviet Union) are in operation in Europe. A minor increase of the installed capacity in both East and West is envisaged by the end of the century, but most of the plants in operation then will be those already existing today. This capacity makes Europe the region of the world with the highest concentration of nuclear plants on a territory with one of the highest population densities.

What are the main problems that Eastern and Western Europe face with nuclear installations now existing on their territories? Where does it appear reasonable to concentrate possible cooperation between Eastern and Western Europe? In the coming 10 to 15 years, governments, institutions, and industries in both Eastern and Western Europe will be called upon to solve problems in three main areas: 1) safe operation of

the plants; 2) decommissioning of the old plants; and 3) waste disposal. The physical protection of nuclear plants from terrorism could be another subject of interest. In all these areas it seems plausible that Eastern and Western Europe have common interests. Let us try to identify them.

Each country is concerned with the safe operation of its own and neighboring nuclear plants. An accident beyond its border, even if less severe than Chernobyl, could endanger its own population and bring about public reactions that could adversely affect the normal development of its own nuclear programs. The effect of the Chernobyl accident on public opinion underscores this point. In all of Europe, East and West, widespread pressure has led to the curtailing of nuclear power expansion in several countries.

On the other hand, a successful nuclear program can foster public confidence. Any failure, however, can undermine the prospects for nuclear energy. One area where cooperation could be intensified is the exchange of nuclear power operating experience. In this area, cooperation should be envisaged and extended beyond the efforts of the IAEA and other international organizations. To gain the maximum benefit from this cooperation, operating experience must first be subjected to in-depth analysis. In terms of existing reactors, cooperation intended to introduce additional technical safety measures (e.g., a filtering-venting system to limit the consequences of core meltdown) should also be examined. The Finnish experience demonstrates that integration of Eastern and Western nuclear technology is possible.

Decommissioning is another potential area for cooperation between Eastern and Western Europe. Several European nuclear plants are scheduled to go out of service in the coming years, unless their planned operating life is extended. They will have to be dismantled and the nuclear waste disposed. In fact, success in decommissioning the old plants will increase confidence in the further development of nuclear power in Europe. Failure or delay in doing so will most probably reduce the chances of the European countries securing energy independence based on nuclear power. Cooperation is therefore of central interest to both sides. Pursuing long-term objectives should be a primary aim. For example, after greater experience, general criteria should be agreed upon for the decommissioning of future reactors. To make decommissioning complete, more economical, and safer, a proper design should be provided before construction. For European countries with limited territories, these precautions seem to be imperative, especially for the further development (or even the maintaining) of nuclear power over the next century. As far as waste disposal is concerned, this is the subject of major public concern. Cooperation can be a means of widening the possibilities of safe and economic waste disposal for both sides.

Common interest might also exist in the protection of nuclear plants from terrorism.[50] In fact, the consequences of a threatened or real terrorist act against a nuclear power plant anywhere might be disastrous for both Eastern and Western Europe. This risk (which some consider exaggerated) has to be of concern to European countries because of the political fragmentation of the continent, the high concentration of nuclear installations, and the high density of population. European countries have a special interest in taking measures that could prevent damage to nuclear installations from terrorist acts.

A second focus for cooperation between Eastern and Western Europe should be the development of future nuclear power. As we have seen, the debate over a new generation of nuclear power plants has spread worldwide after Chernobyl. Now, with most nuclear power programs halted or postponed, this debate is becoming a central issue in nuclear energy policies in the East and West. Though they may disagree on specifics, almost all countries are exploring new possible technological solutions for the future. The development prospects for "evolutionary" and "revolutionary" nuclear reactors with passive and inherent safety characteristics are stimulating new industrial alliances and relations among European industries and countries on the nuclear field.

However, can we envisage an "inherently safe nuclear reactor for Europe" for whose development Eastern and Western European countries might join their technological and human resources and capabilities.

So far, excepting the HTGR and PIUS reactors—which significantly depart from the first commercial nuclear power generation and therefore do not involve already existing interests—few of the new reactor concepts seem to attract attention at the European level.

Although the development and construction of prototype reactors based on these internationally shared new concepts seem to be steadily gaining ground, Europe's main efforts are clearly addressed toward improving the safety and economics of existing plants.

In Europe, as we already have seen, international cooperation on nuclear power is growing on a multipolar basis, making likely a European commitment organized at different levels and led by different countries in reference to different kinds of reactor. A case in point is the development of the HGTR, led so far by West Germany and the USSR.

The successes of Western European cooperation in the space field, where national programs are supplemented by the initiatives of the European Space Agency, and in advanced technologies, where programs such as Eureka are grouping individual national interests and resources, could serve as models for building forms of European cooperation on future nuclear power. Such programs would be open to participation by individual Eastern European countries according to their own interests and capabilities.

Eastern European countries already involved in the "Comprehensive Program for Scientific and Technological Progress of CMEA Member Countries to the Year 2000" showed interest in the Eureka Program even though it was not open to their participation. Eastern European interest in a program for developing nuclear plants in the future should not be any less than it has been for Eureka. Such a program has long-term objectives and does not interfere with current East-West initiatives in the nuclear field. Initial moves might be envisaged in the framework of ongoing negotiations between the European Communities and CMEA, in other international forums, and at bilateral level as well.

During the first phase, Eastern and Western European countries could cooperate on the establishment of the new reactor's general design and safety criteria, adapted to the specific requirements of the European environment. The need to develop a new reactor might be greater some years from now, when it can be expected that energy demand will start to increase again after a period of low energy prices and unclear prospects for nuclear programs due to the impact of the Chernobyl accident.

Given the resurfacing of concerns about energy security, as well as the new attention to environmental problems due to the use of fossil fuels, an agreement among European countries on the general safety aspects of the next generation of nuclear reactors could be a stepping-stone for now and a cornerstone for further technological development. This program might lead the way to future integration of European energy infrastructures and offer an opportunity to all European countries—particularly the less advanced nations—to participate in the development of the next generation of nuclear reactors.

In addition, such an agreement for development of the next generation of nuclear reactors could enhance the safety and the economic performance of nuclear power in the short term as well. In fact, revitalized interest on the part of the less advanced countries in nuclear power over the long term is likely to help reconcile differences existing among European countries, even in the short term, and strengthen their commitment to the safety of existing nuclear power.

Prospects for cooperation along these lines have become evident since 1986, and increasing interaction between East and West has grown significantly over the last two years, as the following examples.

The West Germans and the Soviets signed two nuclear-cooperation government-level agreements in 1986 and in April 1987. In this framework, KWU, the nuclear power building subsidiary of West German's Siemens, received an order from the Soviet Union in 1988 to provide a safety report on its latest "VVER-88", a 1000 MW PWR. This seems to be the first time the Soviet Ministry of Atomic Energy awarded an order to a Western company.[51]

A closer relationship has also developed over the last few years between West Germany and the Soviet Union in the field of high-temperature reactors. In October of 1988, an agreement was signed among the USSR's State Committee for the Utilization of Nuclear Energy, HBR—the German subsidiary of Asea-Brown-Boveri, the Swedish Swiss engineering group—and the Kraftwerke Union, the power division of the Siemens electrical company. The accord marks the first time that Moscow has turned to the West for help in designing atomic power stations and will lead to construction of an experimental modular high-temperature reactor (HTR), with the support of German industry. The two German companies and the Soviet Union also plan to work together to sell the technology to third markets, notably in Eastern Europe. The agreement breaks new ground in the supply of Western technology to the East. Important elements of the agreement, such as high-powered computers built into the HTR operational and safety systems, have yet to be approved by COCOM for transfer to the East. The details of the working arrangements are under discussion, and formal contracts are still being negotiated.[52]

Franco-Soviet cooperation in the industrial aspects of nuclear energy also took significant steps forward after Chernobyl. The umbrella agreement signed by the French Atomic Energy Commission (CEA) and the Soviet State Committee for the Utilization of Atomic Energy (GKAE) in 1967 had produced little of concrete importance and had focused mainly on peripheral aspects, such as fast reactor theory and dry reprocessing. After talks between the parties in 1987[53] and the signing of a Memorandum of Understanding on nuclear power dismantling in June of 1988—the first formal accord for renewed cooperation between France and the Soviet Union—a new umbrella agreement was signed in Moscow in January of 1989; it is possible for specific industrial cooperation on major aspects of nuclear power.[54]

Five concrete areas have been agreed on by the French-Soviet Commission for industrial cooperation: dismantling (beginning with the Armenskaya plant); design of a future reactor (USSR's planned VVER-92); seismic studies (site analysis and component testing); the instrumentation and control system for the Indo-Soviet reactor project; and a nuclear simulator. This new collaboration was on the agenda for Mikhail Gorbachev's planned visit to France in the first half of 1989.[55]

Though limited to the conventional energy sector, another important cooperative initiative was set up by two Italian firms and the Soviets in February of 1989. Ansaldo SpA, a state-owned electrical engineering company, and FATA SpA have agreed to set up a joint venture based in Moscow, 51% owned by the Soviet Ministry of Energy, aimed at expanding and modernizing all types of power stations in the Soviet Union. The agreement provides that in exchange for the technology, the Soviets will export electricity to Italy for the next 15 years.[56]

Other European countries, such as Finland, Sweden, and Denmark, have also signed agreements with the Soviet Union either for industrial and commercial cooperation or for information exchange about nuclear power plants located near common borders.

In addition, ever since Chernobyl U.S. firms have been working to develop contacts with the Soviets. At the end of 1986, Westinghouse signed a memorandum of cooperation in atomic energy generation and safety with the USSR's State Committee for Science and Technology.[57]

A bilateral agreement on nuclear safety cooperation, appended to the general cooperative agreement between the two countries, was signed by the U.S. and the Soviet Union in April of 1988. This agreement, the first on nuclear safety between the U.S. and the Soviet Union, was proposed by the Soviets during talks in Washington in 1987, and it is expected to be followed by agreements between the U.S. and some Eastern European countries. Areas covered by the agreement include: regulatory policies; problems of safety in design; construction, personnel training, operation, and management of civilian reactors; safety research; and matters regarding health and environmental protection.[58]

Cooperation between Eastern and Western European countries has also taken new steps forward in recent years, in parallel with that between Western countries and the Soviet Union. Some examples follow.

East and West Germany have negotiated an accord providing for an exchange of information on unusual levels of radiation in the event of a nuclear accident. The agreement, which had been under negotiation for several years, also provides for cooperation in the safety of nuclear power stations as well as in the storage and disposal of nuclear wastes. The two German states would also inform each other if they planned to put new nuclear plants into service.[59] Furthermore, East and West Germany signed a contract in March of 1988 enabling the unification of the German power grids and freeing West Berlin from the need to produce all its own power. The link between the two German grids will also allow West Germany to export electricity to East Germany starting this autumn, and vice versa from 1992.[60] While this latter proposal is not directly related to nuclear power cooperation, it does demonstrate a common interest for the integration of energy infrastructure.

In June of 1988, the Finnish Voima oy (IVO) and the Hungarian Paks Atomeromun Vallalat (PAV) signed a preliminary agreement to cooperate in marketing the VVER-440 MW reactor in third countries, including the Soviet Union. Both companies operate VVER-440 reactors. As mentioned above, the Finns have improved the safety of their plants through the injection of Western technology.[61]

The Hungarians have signed cooperative agreements for technical assistance in the construction of two 1000 MW units at Paks with France and the United States.[62]

In October 1988, the Italian and Hungarian electricity boards signed an agreement for the exchange of information and documentation and for joint studies on power plants, nuclear included.[63]

The Canadian Atomic Energy Commission of Canada and two Hungarian electric companies are setting up a joint venture aimed at using a small reactor of 10 MW, Slowpoke, for heating purposes. This cooperative venture, which calls for drawing up contracts whereby the Hungarian companies may act as the European marketing agents for the Slowpoke, was made possible by a cooperative agreement on the peaceful uses of nuclear energy signed by the governments of the two countries in November of 1987.[64]

Under a contract between Framatome and Skoda, France and Czechoslovakia are cooperating on the first concrete case involving Czech use of a French structural code technology for fabricating primary circuit components for nuclear power plants.[65]

Broad East-West cooperation was also undertaken after Chernobyl in the field of nuclear power plant operating experience. The U.S. Institute for Nuclear Power Operation (INPO), the Union des Producteurs and Distributeurs Europiens d'Ilectriciti (UNIPEDE), and utilities in the CMEA countries inaugurated the World Association of Nuclear Operators (WANO) in Moscow on May 15, 1989.[66] The Association was proposed after the Chernobyl accident when the world's nuclear power operators came to realize how little contact existed among them. The Association is intended to be a mechanism for rapid exchange of information on nuclear technology and nuclear plant operation through four regional centers, based in Atlanta, Paris, Moscow, and Tokyo. WANO's Coordinating center will be set up in London. The Paris

center was formally established in January of 1989.[67] The Association will complement IAEA initiatives in this field, bypassing governmental channels to allow faster exchange of technical information.

Thermonuclear fusion research is another area where broad East-West cooperation is now developing. EURATOM, Japan, the Soviet Union, and the United States have initiated a broad cooperative program aimed at demonstrating the scientific and technological feasibility of magnetically confined nuclear fusion. A first step should be cooperation in a conceptual design study for an International Thermonuclear Experimental Reactor (ITER). In November of 1988, the ITER council approved "concept definitions," allowing work on conceptual design to proceed.[68]

All these cooperative initiatives are certainly favored by the new openness of the present Soviet leadership, as well as by the growing impact of current technological development with its intrinsic global character.

In fact, the network East-West relations in nuclear power reviewed above reflects the new trends in international cooperation, which is increasingly multipolar in its contents and goals. Today, East-West cooperation in nuclear power is developing at both bilateral and multilateral levels. For Eastern European countries, this broadening network of relations could open new prospects for sharing their specific skills in nuclear power and for participating in the development of nuclear power projects launched by Western European countries. Several other tendencies might also stimulate such cooperation.

After the Chernobyl accident, the Western European nuclear industry faces a slowdown of its programs and the continuing problem of overcapacity in the nuclear power industry. Cooperation with Eastern Europe could offer Western industries prospects for participating in Eastern European nuclear programs. In the wake of Chernobyl, the Soviet Union may be interested in regaining public confidence in nuclear technology and accelerating its development among its allies by allowing them to cooperate with Western countries. Obviously, the East would benefit from the transfer of Western technologies. At the same time, cooperation between the East and West European countries aimed at upgrading the safety of nuclear plants might also have the added effect of restoring the confidence of public opinion in nuclear energy.

For Eastern European countries, cooperation with Western Europe might free resources for the development of other advanced technological sectors and, at the same time, improve the efficiency of their nuclear programs. Eastern Europe has been unable to get enough nuclear plants installed on time. Now, particularly after Chernobyl, the necessary attention to safety may further hamper their plans. In fact, Eastern Europe lags behind Western Europe in the development of nuclear power technologies. Although new efforts were called for in the "Comprehensive Program" adopted in 1985—which gives top priority to nuclear power—it is unlikely that the poor performance of their economies will allow them to meet the goals for nuclear energy production called for in their plans, especially now that widespread pressure to curtail nuclear power expansion is emerging in the Eastern bloc, particularly in the Soviet Union.

Such cooperation might also constitute a vital insurance policy for the West Europeans, in the sense of preventing their nuclear programs from being adversely affected by the nuclear development of the Eastern side, independently of the short term economic and technological benefits derived in return.

In addition, it would be argued that the ongoing nuclear disarmament negotiations might fuel less mistrust among countries in the area of civilian nuclear power development, stimulating new positive ties between the two processes.

CONCLUSIONS

The differences that exist between East and West European organizational and institutional structures in the area of nuclear power are as substantial as the differences in their degree of actual plant development. Eastern Europe's installed nuclear power capacity (43,000 MW) is less than half of that installed in Western Europe (108,000 MW).

An important similarity between their programs is the prevailing construction of plants based on pressurized water reactors: about 130 units of this type are in operation in all of Europe, and 50 are under construction or planned.

However, nuclear power is now expected to develop in Europe at a slower pace than it did before the Chernobyl accident of 1986.

In Eastern Europe, new public concerns, together with old inefficiency problems, weight heavily on the actual construction of planned nuclear power plants.

In Western Europe, the Chernobyl accident speeded the end of a first cycle in the construction of nuclear power plants, an end already in the offing before 1986 due to a number of factors: saturation of power production capacity; a growing interest in coal-fired stations; and political decisions to limit the share of nuclear energy (or to phase it out entirely). Few units are expected to be built in the coming years in Western Europe, where two main prospects dominate: a general commitment to the development of new reactors to be used over the next century and international cooperation.

International cooperation is especially developing at the industrial level, under the pressure of three main factors: world overcapacity in engineering and the production of electromechanical equipment; competition on world markets, which requires companies to be larger and stronger; and the general wave of European industrial and commercial mergers in view of the Single market of 1992.

Cooperation among Eastern and Western European countries has been growing significantly over the last two years, opening new prospects for closer cooperation on the safety of existing nuclear plants and on the development of future nuclear power, in parallel with ongoing improvements in East-West relations.

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HIGHLIGHTS OF 50 YEARS OF NUCLEAR FUEL DEVELOPMENT

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ABSTRACT

The development of nuclear fuels since the discovery of nuclear fission is briefly surveyed in this paper. The fabrication of the uranium fuel for the first nuclear pile, CP-1, is described. The research and development studies and fabrication of the different types of nuclear fuels for the variety of research and power reactors are reviewed. The important factors involved to achieve low fuel-cycle costs and reliable performance in the fuel elements are discussed in the historical context.

INTRODUCTION

The first nuclear chain reacting pile, CP-1, reached criticality on December 2, 1942, only three years after the discovery of fission and. only one year after the chain reactor program was started in the Manhattan Project. In a coded telephone exchange Arthur Compton informed James Conant that "the Italian Navigator" (Enrico Fermi) had landed in the New World and that "the natives were friendly." The success of this experiment was critically dependent on the development and fabrication of uranium fuel (metal and oxide), the production of pure graphite moderator bricks, and the preparation of the radium-beryllium neutron source. The production of these materials for the CP-1 reactor was successfully achieved by the "friendly natives," who were a highly talented group of metallurgists, physicists, and chemists. This was a classic example of interdisciplinary research, and it served as an important model for subsequent research studies to develop nuclear fuels for reactors.

The development of nuclear fuels is primarily the result of the extensive contributions of pioneers from many countries during the past five decades. The goals of low cost and reliable performance in the fuel elements have been achieved. The nuclear fuel elements have accommodated the severe operating conditions set by the designs of the reactor cores, including thermal and mechanical stresses and prolonged exposure to the coolants and nuclear irradiation.

THE FIRST DECADE

The self-sustaining controlled nuclear chain reaction was achieved on December 2, 1942, in the CP-1 uranium-graphite reactor, which was constructed on a squash court under the West Stands of Stagg Field at the University of Chicago. The core of this first pile consisted of layers of graphite blocks (1350 tons) with holes about 20 cm apart in some of the blocks in alternate layers, which contained natural uranium metal rods or uranium oxide cylinders and pseudo-spheres. It was not until November 1942 that any appreciable amount of metallic uranium was available. At the rated power the core loading was 5630 kg of metallic uranium (2060 rods, 5.6 cm diameter x 5.6 cm long) and 36,590 kg of uranium oxide in the form of cylinders and pseudospheres. The research and development of fabrication techniques for uranium metal were initiated in 1942. The main objective was to find a system, using normal uranium, in which a chain

reaction would occur. The early efforts to produce uranium rods by an extrusion process almost ended in disaster: "The uranium billet was initially inserted into the extrusion press container with some difficulty in handling. The temperature of the billet was too low when the full 700 tons pressure was used. The uranium metal came through the die into the run-out chute in a shower of flowing pieces the size of marbles glowing red hot. The "pit" man flew up the 20 foot ladder out of the pit, clothing on fire, and giving a profane lecture that if a group of idiot college professors wanted to catch their experimental rods they could!"

During the first decade (1942-1952) extensive research, development, and production studies were carried out in the US on fuel materials. Fuel elements were fabricated for the three Chicago piles (of which CP-1 and CP-2 were small air-cooled graphite-moderated piles and CP-3 was a heavy-water moderated research reactor built at Argonne National Laboratory), for the production reactors at Hanford, and for the X-10 graphite-moderated air-cooled research reactor at Oak Ridge National Laboratory. These reactors operated with natural uranium fuel. At Los Alamos during this period the aqueous homogeneous water-boiler reactor, LOPO, was the first reactor to operate with enriched fuel.

By the end of the first decade experience had been gained in the US with natural and enriched uranium and plutonium fuels, the importance of the Th/U-233 cycle had been emphasized, light- and heavy-water and graphite moderators had been used, and air, water, and liquid metals had been used as reactor coolants. Studies of a breeder reactor, a helium gas-cooled reactor, and a materials-testing reactor had been initiated.

THE NUCLEAR FUEL CYCLE

The nuclear fuel cycle includes (1) production of nuclear fuel (mining, milling, and enrichment), (2) fabrication of fuel elements, (3) reprocessing and recycling of the spent fuel to recover and raise the uranium and plutonium content, and (4) storage of the radioactive waste. The costs of fuel have been reduced by higher burnups, lower fabrication costs, and an increase in the maximum specific power output of the fuel rods. Fuel assembly prices have not risen because fabrication costs have dropped and thus balanced the rising cost of labor and materials costs. The specific fuel costs have actually decreased with the higher burnups.

Howe listed 14 materials that were developed by 1955, including metallic U-based and Pu-based alloy fuel elements, ceramic systems, and fluid fuel systems. The dominant influence of the US Naval Reactors programs on commercial nuclear technology in the US was initiated in 1946. The successful developments of uranium oxide fuel, of hafnium-free zirconium with low thermal-neutron cross section, and of Zircaloys with good corrosion resistance in water at 300°C were particularly important.

FUEL ELEMENT MATERIALS AND DESIGNS

The nuclear fuels that have been developed for reactors include metallic, ceramic, composite, and liquid fuels. The metallic fuels have been alloyed to improve their resistance to irradiation and corrosion. Ceramic fuels have included the oxides, carbides, oxycarbides, nitrides, and hydrides. Composite fuels include two-phase metallic fuels and dispersions of ceramic fuels in metal, ceramic, or graphite matrices. The ideal goal of inherent safety in nuclear reactors has been shown to be feasible with the proper choice of fuel elements in the reactor design, such as the hydride fuel in the TRIGA research reactor and the coated-particle fuel dispersed in graphite moderator in the HTGR power reactors.

A 1000-MW(e) LWR is fueled with about 9 million uranium dioxide pellets contained in about 150 km of fuel rods clad in Zircaloy tubing. The design of the fuel elements has aimed to achieve the goals of adequate heat transfer, nuclear reactivity, retention of fission products, inherent safety under accident conditions, and retention of structural and mechanical integrity. This process has always been based on an iterative procedure, whereby information from experimental results and operational experiences are factored into the refinement of the design.

The phenomenon of fuel swelling has been studied in great detail. The effects of temperature, thermal gradients, and stress gradients on the nucleation and migration of fission gas bubbles in the fuel matrix have been determined. The bubbles migrate up the thermal gradients toward the fuel center and are held and carried along by lattice defects until they are large enough to escape from or migrate along the defects. Bubble migration has been shown to be by Brownian motion for very small bubbles, by surface diffusion when they are larger, and by an evaporation-condensation process at elevated temperatures in very large bubbles. The phenomenon of fission gas resolution in irradiated fuel has been incorporated into the mechanism. Computer codes have been developed to predict the behavior of nuclear fuels in power reactors. The codes address the complex processes occurring during the life of operating fuel elements as functions of the power histories by rigorous analyses based on first principles. These codes have been well documented and are on file at Argonne National Laboratory. They can be obtained on tape and IBM cards with user's manual.

The most challenging problem in the development of the modeling codes for fuel elements has been the complex effects of neutron irradiation on materials and fuels. The fuel cladding and the structural alloys in fast reactor cores swell through void formation by migration of the vacancies formed by fast-neutron irradiation. This leads to a movement of the cladding away from the fuel and thereby to a reduction of fuel-induced stresses. Radiation-induced creep of the cladding and ducts is also a highly complicated phenomenon.

Corrosion of stainless steel cladding by certain fission products (iodine, cesium) in fast-breeder reactor fuel pins has been experienced and examined in great detail.

There have been very successful developments in recent years to improve fuel performance by means of better fuel management and fuel cycling, advanced fuel design, fuel-cycle cost reduction, and more reliable reactor components. The large-scale production of nuclear fuels, particularly with plutonium and recycled fuel, has involved special mechanized equipment designs, improved shielding, rapid accurate analyses, and continuous accountability. The new fuel-element production facilities have automated remotely controlled fuel-pin fabrication processes with computer-controlled operation from a centralized control room. Fuel pellets can now be inspected by means of rapid test instruments, which perform complete characterization of 100% of core loading pellets. Quality control and quality assurance is being exercised to an increasing degree of sophistication in all stages of production.

During the past five decades the remedies that have been applied to solve the fuels problems have been quite effective. An important example in the LWRs was the solution to the serious problem of cladding collapse resulting from radiation-enhanced densification of the oxide fuel pellets. Stable fuel pins were developed by control of the grain size, pore structure, and density of the pellets and by back-filling the cladding with pressurized helium gas in order to prevent collapse of the cladding and to improve the thermal conductivity of the gap. Much higher burnups (over 4000 Gj/kg M) and longer fuel cycles (18 to 24 month cycles) have been achieved in recent years in many LWRS. The incorporation of a thin zirconium barrier between the fuel and the cladding has allowed the successful accommodation of power ramps and cycling to peak power.

RESEARCH REACTOR FUELS

The fuels that have been used in research reactors have included uranium and plutonium metal and alloys, oxides, cermets, hydrides, and aqueous homogeneous solutions (uranyl sulfate, nitrate, or phosphate). The limited availability of enriched uranium fuel and of heavy-water moderator in the early days of reactor development led to the design and construction of several natural-uranium-fueled, graphite-moderated, air-cooled research reactors, such as the 3-5 Mw X-10 reactor at Oak Ridge and the 28-MW Brookhaven Research Reactor. However, the much higher cost per unit flux did not justify continuing with natural uranium fueled graphite reactors.

The pool-and tank-type light-water moderated and cooled research reactors are the most commonly used in most countries. The prototypes of these reactors were first designed and built at Oak Ridge in 1946 as part of the program to build the materials test reactor (MTR). In a typical MTR-type core, the fuel is composed of enriched uranium in aluminum.

In 1962 the research reactor in Puerto Rico was the first to use UO in aluminum cermet fuel. The same fuel was used in the following year in the 250-MW Advanced Test Reactor (ATR) in Idaho. The most sophisticated and complex version of this cermet fuel was fabricated for the 100-MW thermal HFIR at Oak Ridge, which went critical in 1965. It generates the highest thermal neutron flux of any research reactor in the world. It was a remarkable achievement to produce the fuel plates for the HFIR, which are formed as involute curves and fastened in two annular cylinders. The fuel loading in the plates is graded in the radial direction and, in addition, the inner plates contain boron carbide as a burnable poison. These fuel elements have a life of only two weeks in the reactor. The ATR fuel elements are similar to the HFIR elements, except that the uranium oxide loading is uniform. However, each fuel plate in the ATR elements has a different radius. A relatively simple, small (10 kW) research reactor, which used 20% enriched UO-aluminum cermet fuel containing 40 wt% UO (called Argonaut) was designed and built by Argonne national Laboratory and operated from 1957 to 1972.

Many heavy-water-moderated research reactors have been built in the US and 15 other countries since the CP-3 reactor was built at Argonne in 1944. The fuel elements for these reactors included natural and enriched fuel and uranium metal, U-Al alloys, and uranium oxide. The 25-MW HBWR, built in Norway in 1959, is the only heavy-water-moderated research reactor in which the coolant is pressurized boiling heavy water (250°C). It utilizes cylindrical fuel pins with 1.5% enriched uranium oxide pellets clad in Zircaloy-2 and helium bonded. The 33-MW NRX reactor has operated at Chalk River since 1948. Three types of fuel have been used in the NRX: natural uranium metal, enriched U-Al alloy, and Pu-Al alloy. One of the first Pu-Al fuels melted right through two sheaths and the reactor tank! The largest heavy-water-moderated research reactor is the 200-MW NRU, which has operated at Chalk River in Canada. The fuel consists of 305 cm long flat bars of Al-clad natural uranium of variable width and breadth placed in coolant channels. The 60-MW high-flux Grenoble reactor in France uses fully enriched U-Al with boron carbide burnable poison and is clad with an aluminum alloy. The core configuration is annular with plate elements in the shape of involutes of a circle, around a hollow central cylinder The plutonium recycle test reactor (PRTR) at Hanford was a 70-MW pressure-tube type test reactor cooled and moderated by heavy water. It was used to test U-Pu mixed-oxide fuel and operated very successfully from 1960 to 1969, demonstrating the feasibility and economy of recycling plutonium in thermal reactors.

The TRIGA research reactor was conceived and developed at General Atomics after it was founded in 1956. The objective was to provide an inherently safe core composition that had a large prompt negative temperature coefficient of reactivity such that if all the available excess reactivity were suddenly inserted

in the core, the resulting fuel temperature would automatically cause the power excursion to terminate before any core damage resulted. Experiments demonstrated that the integral fuel-moderator system of the uranium-zirconium-hydride fuel possesses a basic neutron-spectrum-hardening mechanism to produce the desired characteristics. This fuel also has a good heat capacity,.excellent irradiation stability and fission product retentivity, high chemical inertness in water, and low hydrogen equilibrium pressures at elevated temperatures. The first 100-kW TRIGA reactor was developed and built in just a year and a half and was critical in 1958. The TRIGA reactor was also shown to have the capability of operation under conditions of transient experiments for delivery of high-intensity bursts of neutrons. It was part of the US exhibit at the second Geneva Conference in 1958. Since then, over 60 TRIGA reactors have been operated in 22 countries, the largest one being the 14-MW unit in Romania.

A number of liquid-metal-cooled small experimental fast reactors have been built and operated successfully. These reactors have used Pu, enriched U, or Pu+U mixed fuel and were cooled with air, mercury, sodium, or NaK. The first fast reactor experiment was the 25-kW Clementine at Los Alamos. operated from 1946 to 1953. It was fueled with stabilized delta-phase Pu. The fuel was in the form of nickel-plated rods. The core was surrounded with natural U rods of the same dimensions and was cooled with mercury. Los Alamos also operated the 1-MW LAMPRE-1 reactor from 1961 to 1963. It was fueled with molten eutectic alloy of Pu with 2.4 wt% Fe having a melting point of 410° C, contained in tantalum capsules which were cooled with sodium.

POWER REACTOR FUELS

Carbon-Dioxide Gas-Cooled Reactors

The first generation of commercial nuclear power reactors in Britain and France are cooled by carbon-dioxide gas and fueled with natural uranium metal rods clad in magnesium alloys. Graphite is the moderator material in these reactors. The first of these reactors (Calder Hall) started generating electricity in 1956. The uranium was alloyed (1%) with small quantities of Fe, Al, C, Si, and Ni to improve its irradiation resistance. The second-generation CO_2-cooled graphite-moderated reactors in Britain (the AGRS) use slightly enriched UO clad in a special stainless steel. These fuel elements can operate at higher temperatures to much greater burnups, giving higher efficiencies and ratings.

Helium Gas-Cooled Reactors

From 1944 to 1946 a design for an advanced helium gas-cooled power-reactor concept was developed at Oak Ridge. The proposal was to use natural uranium carbide as fuel, graphite and BeO as moderators, and helium as coolant with a direct-cycle gas-turbine energy-conversion system. The project was cancelled in 1946, and it was revived a decade later in the US (Peach Bottom, Ft. St. Vrain, UHTREX), Britain (Dragon), and West Germany (AVR, THTR). The high-temperature gas-cooled reactors (HTGR) use helium gas as the primary coolant, graphite as the neutron moderator and fuel-element structural material, and coated carbide or oxide fuel particles dispersed in a graphite matrix. The choice of graphite as the moderator and core structural material is based on its unique chemical, physical, and mechanical properties at elevated temperatures and on its very low neutron cross section, good radiation stability, ease of fabrication, and low cost. The use of graphite as a diluent of the fuel permits much greater fuel dilution than would otherwise

be possible and thereby minimizes radiation damage, increases specific power, and greatly extends the heat transfer surface. The Th/U-233 standard fuel cycle (with U-235 as the initial fissionable fuel) is used because of its potential for achieving a higher fuel utilization.

The coated-particle fuel allows the high-temperature operation of the core to very high burnup (80%) of the fissile fuel, with extremely high retention of the fission products. The average fuel burnup of 100 MWd/kg obtainable is by far the highest of all existing thermal-reactor systems. In recent years the design and development effort has been focused on a modular smaller-power (130 MW(e)) concept, the MHTGR. In this second-generation nuclear power system the safety and protection will be provided by inherent and passive features, independent of operator actions or the activation of engineered systems.

In the MHTGR the active core region is composed of graphite fuel element blocks that are hexagonal in cross section, 35 cm across the flats and 77 cm long. The fuel is in the form of coated particles, 800 microns in diameter. Each fuel particle consists of a uranium oxycarbide kernel (350 microns in diameter) first coated with a porous graphite buffer, followed by three successive layers of pyrolytic carbon, silicon carbide, and pyrolytic carbon. Similar, but slightly larger coated particles containing a kernel of thorium oxide are also used in the reactor. The coated particles are mixed with a graphitic material, formed into fuel rods, 1.25 cm in diameter and 5 cm long, and then inserted into sealed holes in the graphite fuel element blocks. Vertical coolant holes are also provided in the fuel-element blocks. The fuel elements are stacked in columns to make up an annular shaped core. Unfueled graphite blocks surround the active core to form replaceable inner and outer radial and axial reflectors. The massive graphite structure provides a large heat sink during transient conditions.

The inherent safety is also achieved by virtue of the single phase and inertness of the helium coolant and the negative temperature coefficient of reactivity. In addition to the redundancy in the cooling system, the decay heat can be removed passively by means of conduction, radiation, and natural convection without the core temperature exceeding the fuel-damage temperature.

In Germany two pebble-bed helium-cooled reactors (AVR and THTR) have been developed and built with spherical, graphite matrix fuel elements surrounded by bottom and side graphite reflectors. The fuel elements consist of pyrolytic carbon-coated carbide fuel particles dispersed in a graphite matrix and encased in spherical graphite balls, 6 cm in diameter. These reactors have performed very well; the AVR operated for about twenty years and attained coolant temperatures of up to 1000°C. The UHTREX reactor at LANL attained 1300°C.

Light Water Reactor Fuels

The light-water pressurized and boiling reactors (PWR and BWR) in operation and under construction account for the largest share of nuclear power generation in most countries. The first land-based PWR prototype, the STR, was started in Idaho in 1953. The APS-1 prototype at Obninsk, USSR, was originally operated in 1954 as a PWR power reactor and was later converted for boiling water and nuclear superheat. The Shippingport PWR was authorized in 1954 and commenced operation in 1957.

Although metallic cermet fuels (Zircaloy-2 matrix with 6.3 wt.% U) were used in a few of the early PWR cores in the US, the majority are fueled with uranium dioxide clad with Zircaloy. The zirconium alloys were developed for water reactors because of their low neutron cross section, adequate strength in the operating temperature range, and satisfactory resistance to irradiation and to corrosion by water at high temperatures. The many improvements and refinements in core design led to greater power densities, fuel assemblies with higher integrity, more effective fuel management and fuel cycling, chemical shim control

(using boric acid in solution in the PWR coolant), and rod cluster control. The Th-U-233 cycle has been shown to improve the conversion ratio significantly. The operational experience with mixed oxide (U, Pu)O fuel has been excellent.

The Shippingport PWR cores have provided extensive operating experience on a large-sized PWR nuclear power plant. This reactor furnished the incentive for the development of and the vehicle for evaluation of the Zircaloy-clad uranium-oxide fuel rod, which is the basic fuel element for the commercial water-cooled power reactors of the world today. The "seed-and-blanket" core in this reactor consisted of "seed" regions containing fully enriched (93%) uranium surrounded by blanket regions consisting of natural fuel lattices.

The prototype PWR version of the 5-mWe APS first operated in the USSR in 1954 with a fuel which consisted of a 5% enriched U-9%Mo alloy powder dispersed in a magnesium matrix. The fuel elements were annular-tube shaped, with thicker inner and thinner outer claddings of stainless steel. A typical fuel channel consisted of four elements arranged in a square array in a graphite moderator structure, which contained a stainless steel tube in the center for carrying the primary circuit water to the inlet and outlet headers.

The first experimental boiling water reactor in the US, the 5-MW(e) EBWR, operated from 1956 to 1967 at Argonne. The fuel elements for the initial core included highly enriched rod-type "spike" elements and 1.44% enriched plate-type elements. The fuel in the spike elements was a ceramic-oxide fuel clad in Zircaloy-2, and in the plate-type elements the fuel was an alloy of U-5%Zr-1.5%Nb metallurgically bonded to the Zircaloy-2 cladding. In 1966 the EBWR was the first BWR to use Pu fuel in the form of mixed oxide fuel rods in an electricity generating reactor. The 5-MWe Vallecitos BWR was a prototype reactor built and operated by General Electric from 1957 to 1963.

The background of experience with light-water reactor-fuel exposure by 1985 had reached an estimated 56,000 PWR fuel assemblies (13 million rods) and 10,000 BWR assemblies (6 million rods). Fuel failure rates have decreased from 0.012% to 0.001% in PWRs and from 0.023% to 0.001% in BWRS. Lead test assemblies have been irradiated to over 60 GWd/t in PWRs and to over 45 GWd/t in BWRs. In-reactor exposures of fuel assemblies for as long as six equivalent full power years in a BWR and over five years in a PWR have been achieved. These assemblies appeared to be in excellent condition, and their life expectancy was limited only by the differential growth of the Zircaloy under irradiation. Appropriate design improvements could eliminate such limitations and allow even longer exposures of the fuel assemblies.

In the PWRs fuel damage is primarily caused by fabrication defects, by fretting and wear from the deposition of impurities and debris in the core, and by core baffle-jetting. Handling damage of fuel assemblies has also been a problem during refueling operations, which has led to more accommodating designs and improved operating procedures. In the BWRs in the 1960s and 1970s major losses of capacity factor were experienced as a result of failures caused by clad hydriding and by fuel-pellet-clad interaction (PCI) phenomena, as well as by stress corrosion cracking of pipe welds. These problems have been addressed successfully, such that fuel problems are no longer a significant cause of capacity factor losses.

The recent developments have resulted in the design and fabrication of more forgiving fuel elements for water-cooled reactors, such as the incorporation of a thin barrier liner (zirconium) inside the cladding, prepressurization of the fuel pin with helium gas, fuel-pellet design changes, and changes in the fuel-assembly designs so as to lower fuel temperatures. The use of burnable poisons (Gd) in the fuel has enabled control of the large excess reactivity required at initial startup with high fuel exposure cores.

Heavy-Water Reactor Fuels

The use of heavy water as a moderator provides good neutron economy and permits a wide range of possible fuel cycles and fuel management schemes. The most ambitious and pioneering work in the development of heavy-water-moderated power reactors has been in Canada. The 25-MW(e) NPD reactor was Canada's first nuclear power demonstration reactor (1962). It was built to demonstrate the concept of a horizontal pressure-tube reactor, moderated and cooled by heavy water and fueled with natural-uranium-dioxide pellets contained in Zircaloy-2 cladding, operating on a once-through basis with on-power refueling. The pressure tubes used were the Zr-2.5%Nb alloy developed in the USSR. The fuel elements have performed very well in the CANDU reactors. The fuel elements are made up of bundles of 28 rods. The maximum fuel-rod rating is about 690 W/cm. The fuel temperature is 400° C surface and 2000° C center. A recent modification has significantly improved the fuel's performance. The new fuel rods include a thin layer of graphite between the fuel and the cladding, designated CANLUB fuel. This minimizes local stress concentrations and also protects the cladding against fission-product (iodine) attack. Another important contribution was the work on how directionally oriented hydrides in Zircaloy affect the deformation behavior. Specifications were then produced for cladding with controlled hydride orientation.

Fast-Breeder-Reactor Fuels

The concept of breeding plutonium in a fast reactor dates back to 1944, when Fermi and Zinn discussed the possibility of building a fast-neutron breeder reactor. Fast breeder reactors increase fuel usage to over 70% of the uranium employed, compared with about 1% in thermal reactors. In a 30-year period, a fast breeder reactor of 1000-MW(e) capacity would require about 23 tons of uranium compared with 3000 tons in a light-water-cooled reactor. The fuel-cycle cost is also expected to be significantly lower in fast-breeder power reactors than in thermal reactors or in fossil-fueled power stations. The cost of power is not strongly influenced by the cost of uranium in fast breeder reactors. Although the technical feasibility and advantages of the fast breeder reactor have been demonstrated, the goal of the fast-breeder-reactor programs has been to improve the technology to build economically viable fast breeder reactors in the near future.

In 1946 the developmemt of the experimental breeder reactor, EBR-I, was started at Argonne National Laboratory; construction began in 1949 at the National Reactor Testing Station in Idaho, and the reactor went critical in mid-1951, a total of 5 years! Nowadays it would take that long just for the paper work and the hearings for such a project. The EBR-I reactor produced the first usable amounts of electricity (200 kill) to be generated from a nuclear reactor (December 20, 1951) and demonstrated the feasibility of breeding plutonium in a fast reactor. Fast breeder (FBR) power reactor prototypes have been built in the US, UK, USSR, France, Germany, Japan, and India. The largest operating FBR is the 1300-MW(e) Super-Phoenix in France.

Following the shutdown of EBR-I in 1963, the 20-MW(e) EBR-II reactor began operation in 1964. A unique feature of the EBR-II is that it is located adjacent to a fuel cycle facility for pyrometallurgical reprocessing, recovery of the fertile and fissile materials, and reenrichment and refabrication of fuel elements for return to the reactor. The shielded, remotely controlled pyrometallurgical facility can handle high-burnup short-cooled fuels, and thereby improve fuel-cycle costs by avoiding high inventory charges. The core-1 fuel loading was the 43% enriched alloy U-11 at.% "fissium" corresponding to the mixture of fission products that are not removed in the refining process, and its composition changes as Pu is added or builds into the fuel. The fuel is sodium-bonded to the stainless steel cladding, and an inert gas plenum is provided to accommodate sodium expansion and fuel swelling. The fuel smear density is 75% and the linear heat

rating is 20 to 60 Kw/m. Advanced fuels for the EBR-II have included the successful use of U-10Zr, U-8Pu-10Zr and U-19Pu-10Zr, which are compatible with stainless steel cladding up to 800° C. These alloys have tolerated very high burnups of up to 18.4 at.% in the EBR-II when clad with type Dq stainless steel, and 14.3 at.% clad in HT9. Tests are in progress in the FFTR fast test reactor at Hanford, where burnups of up to 10.2 at.% have been achieved with these fuels. The axial swelling of the fuel appears to saturate at 10% when clad in Dq or HT9. The diametral increase is under 1 % at 10 at.% burnup and 5 to 8% at 18.4 at.% burnup. About 60 to 80% of the fission gases are released above 6 at.% burnup.

The 12-MW(e) experimental fast breeder reactor at Dounreay, UK, operated from 1959 to 1980. It was one of the most successful experimental reactors in terms of the wealth of data it provided on fuel elements, materials, kinetics and physics of fast reactors, and the sodium coolant. The fuel elements were vented to allow fission gas release to the sodium coolant. The 300-MW(e) PFR in the UK has operated successfully as a prototype commercial FBR using uranium-plutonium mixed-oxide fuel.

The first prototype FBR in France was the Rapsodie reactor (40-MW(e)), which started operation in 1967. Since then France has rapidly built up on this experience to design and operate the highly successful 300-MW(e) Phoenix and the 1300-MW(e) Super-Phoenix. The fuel used in the FBRs in France is stainless steel-clad mixed oxide (25 wt. % PuO).

In the USSR the development of FBRs has been given a high priority since the 1950s. The 5-MWt SBR-5 reactor is the fifth of a series of small fast reactor experiments. It has operated with stainless steel clad plutonium dioxide, mixed-oxide fuel, and with carbide fuel. During 1962 to 1964 the reactor was intentionally operated with leaking fuel elements and the distribution of fission products in the primary system was determined as a function of power level. Large FBRs have also been built and are operating in the USSR at power levels of 300-MW(e) and 600-MW(e).

The 400-MWt Fast Flux Test Facility (FFTF) at Hanford has served as a most powerful tool for irradiation testing of fuels and materials for commercial FBRS. The advanced mixed oxide fuel clad in the stainless steel alloys Dq and HT9 have attained burnups of up to 20%.

The thermionic and thermoelectric direct conversion space nuclear power reactors have been under development in the US and the USSR. The fuels and materials research studies for these systems have been the most challenging. Good progress has been made during the past two decades.

CONCLUSION

The better load following, and the capacity for extended burnups and longer reactor cycles, have been especially important factors in lowering the fuel-cycle costs and in improving the economics of nuclear power.

The distinguished metallurgist and pioneer in this field, Dr. Cyril Stanley Smith, has made the cogent comment that metallurgy has gained more than it has contributed in its fruitful association with the field of nuclear energy. He has stated that "the core of the problem is the core of the reactor ... the production of serviceable fuel elements, coolants, and moderator ... The solution of the materials problems of the reactor core has called for a skill approaching that of the artist in creating a balance between possibilities and needs, and the highest craftsmanship has been evoked in making the finished components."

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VULNERABILITY ANALYSIS FOR AIRBORNE ACCIDENTAL RELEASE OF HAZARDOUS CHEMICALS

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ABSTRACT

The paper deals with the development of a heavy-gas-dispersion model, which has been used to prepare a chart or nomogram, that gives safe distances in the case of accidental release of chlorine. The nomogram is based on quantity released and meteorological conditions. The meteorological scenario for the whole year has been subdivided into 24 categories, which are easily discernible to a layman so that the nomogram can be used in emergencies (arising from accidental release of Cl_2 by employees working at a plant where chlorine is stored in large quantities).

INTRODUCTION

A number of industrial accidents due to the storage of toxic material have been reported all over the world. In India, several industrial chemical accidents during the last couple of years have attracted attention. Among these, the 1984 Bhopal Gas Tragedy, undoubtedly the worst ever industrial disaster in the history of mankind, tops the list. Even after the Bhopal Gas Tragedy, the situation in India is not very satisfactory in spite of constant efforts by the government and plant authorities and other relevant organizations. This can be illustrated by examining the data on incidents of chemical leakages that have been occurring. For example, from March to December 1985 for the 48 cases of chemical leakages reported, there were 10 persons killed, 234 injured, and 1 138 affected.[1] The chemicals involved include Cl_2 (13 times), NH_3 (6 times), SO_3 (3 times), oleum (2 times), phosgene (once), unidentified chemicals (7 times), and 16 less commonly known/used toxic chemicals. In this context, adequate information regarding "zone of influence" can be provided using appropriate dispersion models that simulate all possible kinds of accidents and leakages. However, the prediction of dispersion scenarios in the context of toxic chemicals that are stored in industrial sites with the help of mathematical models is quite complex. This is mainly due to the following reasons:[2]

1. The material is usually stored as a liquid, so that the volume of gas evolved is very large.
2. The modes of release can vary widely from a ruptured pipe to a complete tank failure, all of which need careful study.
3. The process of formation of the gaseous cloud involves the phase transformation from liquid to gas. This can occur in several ways, from a flashing jet entraining air to the evaporation of a pool by heat transfer from the substrate. Moreover, it is difficult to assess whether a single process or a combination of release and dispersion processes are taking place at the time of an accident.

4. In some cases, chemical transformation may also take place as a result of reaction with water vapor or other species in the ambient atmosphere.
5. The physical properties of the material usually result in the formation of a denser-than-air (i.e., negatively buoyant) cloud, compared to the neutrally or positively buoyant gases encountered in day-to-day pollution problems. The negative buoyancy can have a significant effect on the dispersion characteristics.
6. The release is often very rapid or of transient duration, compared to the steady-state releases in most pollution problems. This gives rise to the complication of predicting dispersion for time-varying releases and the consequential uncertainty in the predictions the result from this variability.
7. The dispersing gas, where it is denser than air, forms a low-level cloud which is sensitive to the effects of manmade and natural obstructions.

Therefore, one needs to study the various factors involved during a chemical accident in detail for modeling the atmospheric dispersion of a toxic gas cloud. In the present study, the main thrust has been given to the catastrophic releases of Cl_2. At this juncture, we would like to point out two important key components for estimating the consequences of an accident:

1. the input parameters for the dispersion calculation for any postulated event, e.g., emissions and the relevant meteorological parameters, and
2. the mathematical model for predicting the concentration of gas as a function of space and time.

MODEL FOR CATASTROPHIC RELEASE

A heavy-gas-dispersion model has been developed at IIT Delhi,[2] which incorporates the gravity-slumping phase, air entrainment, cloud heating, and passive dispersion.

RESULTS

Based on the model formulated above isotons for Cl_2 are given in Fig. 1 that depend on the weather conditions prevailing at the time of the accident. Catastrophic release is assumed in this formulation, and the entire year's weather scenario is categorized into 24 classes (Table 1), which can be easily discerned by a nonspecialist on the basis of the season, time of the accident, cloud cover, and wind speed. These isotons are meant to be used in emergencies requiring evacuation.

TABLE 1: CLASSIFICATION OF THE METEOROLOGICAL SCENARIOS OF THE ENTIRE YEAR

SCENARIO NO.	SEASON	TIME (IST)	WINDS*	CLOUD COVER	METEOROLOGICAL CONDITIONS	SCENARI NO.
1.	Winter	1200-1400 hrs	ω_1	0-1/2	AS - A	1.
	Summer	1100-1500 hrs		0-1/2	WSC - (0.6-1.78) ms^{-1}	
2.	Winter	1200-1400 hrs	ω_2	0-1/2	AS - (A-B)	2.
	Summer	1100-1500 hrs		0-1/2	WSC - (1.9-3.5) ms^{-1}	
3.	Winter	1200-1400 hrs	ω_3	0-1/2	AS - B	3.
	Summer	1100-1500 hrs		0-1/2	WSC- (3.5-5.2) ms^{-1}	
4.	Winter	1200-1400 hrs	ω_4	0-1/2	AS - C	4.
	Summer	1100-1500 hrs		0-1/2	WSC - (5.3-7.4) ms^{-1}	
5.	Winter	1200-1400 hrs	ω_5	0-1/2	AS - C	5.
	Summer	1100-1500 hrs		0-1/2	WSC - (7.5-9.8) ms^{-1}	
6.	Winter	(i) 1200-1400 hrs		> 1/2	AS - (A-B)	6.
		(ii) (1000-1200) & (1400-1600) hrs		0-1/2	WSC - (0.6-1.78) ms^{-1}	
			ω_1			
	Summer	(i) 1200-1400 hrs		> 1/2		
		(ii) (0900-1100) & (1500-1700) hrs		0-1/2		
7.	Winter	(i) 1200-1400 hrs		> 1/2	AS - B	7.
		(ii) (1000-1200) & (1400-1600) hrs		0-1/2	WSC - (1.9-3.5) ms^{-1}	
			ω_2			
	Summer	(i) 1100-1500 hrs		> 1/2		
		(ii) (0900-1100) & (1500-1700) hrs				
8.	Winter	(i) 1200-1400 hrs		> 1/2	AS - (B-C)	8.
		(ii) (0900-1100) & (1400-1600) hrs		0-1/2	WSC - (3.5-5.2) ms^{-1}	
			ω_3			
	Summer	(i) 1100-1500 hrs		> 1/2		
		(ii) (0900-1100) & (1500-1700) hrs		0-1/2		
9.	Winter	(i) 1200-1400 hrs		> 1/2	AS - (C-D)	9.
		(ii) (1000-1200 & (1400-1600) hrs		0- 1/2	WSC - (5.3-7.4) ms^{-1}	
			ω_4			

* Meaning of the symbols in this column have been explained at the end of this table.
AS - Atmospheric Stability
WSC - Wind Speed Class (mid-point value taken)

	Summer	(i) 1100-1500 hrs (ii) (0900-1000) & (1500-1700) hrs		> 1/2 0-1/2	
10.	Winter	(i) 1200-1400 hrs (ii) (1000-1200) & (1400-1600) hrs		> 1/2 0-1/2	AS - D WSC - (7.5-9.8) ms^{-1}
			ω_5		
	Summer	(i) 1100-1500 hrs (ii) (0900-1090) & (1500-1700) hrs		> 1/2 0-1/2	
11.	Winter	(i) (1000-1200) & (1400-1600) hrs (ii) 2 hrs after sun- rise to 1000 hrs and 1600 hrs to 1 hr before sun- set		> 1/2) any amount but not overcast	AS - B WSC - (0.6-1.78) ms^{-1}
			ω_1		
	Summer	(i) (0900-1100) & (1500-1700) hrs (ii) 1 hr after sun- rise to 0900 hrs and 1700 hrs to 1 hr before sun- set		> 1/2 any amount but not overcast	
12.	Winter	(i) (1000-1200) & (1400-1600) hrs (ii) 1 hr after sun- rise to 100 hrs and 1600 hrs to 1 hr before sun- set		> 1/2 any amount	AS - C WSC - (1.9-3.5) ms^{-1}
			ω_2		
	Summer	(i) (0900-1100) & (1500-1700) hrs (ii)1 hr after sun- rise to 0900 hrs and 1700 hrs to 1 hr before sun- set		> 1/2 any amount	
13.	Winter	(i) (1000-1200) & (1400-1600) hrs (ii) 2 hrs after sun- rise to 1000 hrs and 1600 hrs to		> 1/2 any amount	AS - C WSC - (3.5-5.2) ms^{-1}

		1 hr before sunset			
			ω_3		
	Summer	(i) (0900-1100) & (1500-1700) hrs	> 1/2		
		(ii) 1 hr after sunrise to 0900 hrs and 1700 hrs to 1 hr before sunset	any amount		
14.	Winter	(i) (1000-1200) & (1400-1600) hrs	> 1/2	AS - D WSC - (5.3-7.4) ms^{-1}	14.
		(ii) 2 hrs after sunrise to 1000 hrs and 1600 hrs to 1 hr before sunset	any amount		
			ω_4		
	Summer	(i) (0900-1100) & (1500-1700) hrs	> 1/2		
		(ii) 1 hr after sunrise to 0900 hrs and 1700 hrs to 1 hr before sunset	any amount		
15.	Winter	(i) (1000-1200) & (1400-1600) hrs	> 1/2	AS - D	10.
		(ii) 2 hrs after sunrise to 1000 hrs and 1600 hrs to 1 hr before sunset	any amount	WSC - (7.5-9.8) ms^{-1}	
			ω_5		
	Summer	(i) (0900-1100) & (1500-1700) hrs	> 1/2		
		(ii) 1 hr after sunrise to 0900 hrs and 1700 hrs to 1 hr before sunset	any amount		
16.	Winter	(i) Period between 1 hr after sunrise to 2 hrs after sunrise	any amount	AS - D WSC - (0.6-1.78) ms^{-1}	15.
		(ii) Within 1 hr before	any amount		

		sunset			
			ω_1		
	Summer	Within 1 hr before sunset or after sunrise		any amount	
17.	Winter	(i) Period between 1 hr after sunrise to 2 hrs after sunrise		any amount	AS - D WSC - (3.6-5.6) ms^{-1}
		(ii) Within 1 hr before set		any amount	
			ω_1		
	Summer	Within 1 hr before sunset or after sunrise		any amount	
18.	Winter	(i) Period Between 1 hr after sunrise to 2 hrs after sunrise		any amount	AS - D WSC - (1.9-3.5) ms^{-1}
		(ii) Within 1 hr before sunset		any amount	
			ω_3		
	Summer	With 1 hr before sunset or after sunrise		any amount	
19.	Winter	(i) Period between 1 hr after sunrise to 2 hrs after sunrise		any amount	AS - D WSC - (5.6-7.9) ms^{-1}
		(ii) Within 1 hr before sunset		any amount	
			ω_4		
	Summer	Within 1 hr before sunset or after sunrise		any amount	
20.	Winter	(i) Period between 1 hr after sunrise to 2 hrs after sunrise		any amount	AS - D WSC - (8.0-10.5) ms^{-1}
		(ii) Within 1 hr before sunset		any amount	
			ω_5		
	Summer	Within 1 hr before sunset or after sunrise		any amount	

21.	Winter	2 hrs after sunrise to 1 hr before sunset (during the day)		overcast	AS - C WSC - (0.6-1.78) ms^{-1}	20.
			ω_1			
	Summer	1 hr after sunrise to 1 hr before sunset (during the day)		overcast		
22.	Winter	2 hrs after sunrise to 1 hr before sunset (during the day)		overcast	AS - C WSC - (1.9-3.5) ms^{-1}	12.
			ω_2			
	Summer	1 hr after sunrise to 1 hr before sunset (during the day)		overcast		
23.	Winter	2 hrs after sunrise to 1 hr before sunset (during the day)		overcast	AS - C WSC - (5.3-7.4) ms^{-1}	13.
			ω_3			
	Summers	1 hr before sunrise to 1 hr before sunset (during the day)		overcast		
24.	Winter	2 hrs after sunrise to 1 hr before sunset (during the day)		overcast	AS - D WSC - (5.3-7.4) ms^{-1}	14.
			ω_4			
	Summer	1 hr after sunrise to 1 hr before sunset (during the day)		overcast		
25.	Winter	2 hrs after sunrise to 1 hr before sunset (during the day)		overcast	AS - D WSC - (7.5-9.8) ms^{-1}	10.
			ω_5			
	Summer	1 hr after sunrise to 1 hr before sunset (during the day)		overcast		

26.	Winter	Night + 1 hr after sunrise		overcast	AS - D WSC - (0.6-1.78) ms^{-1}	15.
			ω_1			
	Summer	Night		overcast		
27.	Winter	Night + 1 hr after sunrise		overcast	AS - D WSC - (1.9-3.5) ms^{-1}	16.
			ω_2			
	Summer	Night		overcast		
28.	Winter	Night + 1 hr after sunrise		overcast	AS - D WSC - (3.6-5.6) ms^{-1}	17.
			ω_3			
	Summer	Night		overcast		
29.	Winter	Night +1 hr after sunrise		overcast	AS - D WSC - (5.6-7.9) ms^{-1}	18.
			ω_4			
	Summer	Night		overcast		
30.	Winter	Night + 1 hr after sunrise		overcast	AS - D WSC - (8.0-10.5) ms^{-1}	19.
			ω_5			
	Summer	Night		overcast		
31.	Winter	Night + within 1 hr after sunrise	ω_1	any amount but not overcast	AS - F WSC - (0.7-2.0) ms^{-1}	21.
32.	Winter	Night + within 1 hr after sunrise	ω_2	< 1/2	AS - F WSC - (2.0-3.6) ms^{-1}	22.
33.	Winter	Night + within 1 hr after sunrise	ω_2	> 1/2	AS - E WSC - (2.0-3.6) ms^{-1}	23.
34.	Winter	Night + within 1 hr after sunrise	ω_3	< 1/2	AS - E WSC - (3.7-5.7) ms^{-1}	24.
35.	Winter	Night + within 1 hr after sunrise	ω_3	> 1/2	AS - D WSC - (3.6-5.6) ms^{-1}	17.
36.	Winter	Night + within 1 hr after sunrise	ω_4	any amount	AS - D WSC - (5.6-7.9) ms^{-1}	18.
37.	Winter	Night + within 1 hr after sunrise	ω_5	any amount	AS - D WSC - (8.0-10.5) ms^{-1}	19.
38.	Summer	Night	ω_1	any amount	AS - D WSC - (0.6-1.78) ms^{-1}	15.

39.	Summer	Night	ω_2	any amount	AS - D WSC - (1.9-3.5) ms^{-1}	16.
40.	Summer	Night	ω_3	< 1/2	AS - D WSC - (3.6-5.6) ms^{-1}	17.
41.	Summer	Night	ω_3	> 1/2	AS - C WSC - (3.5-5.2) ms^{-1}	13.
42.	Summer	Night	ω_4	any amount	AS - C WSC - (5.3-7.4) ms^{-1}	4.
43.	Summer	Night	ω_5	any amount	AS - C WSC - (7.5-9.8) ms^{-1}	5.

ω_1	Light Air	: Wind is not felt on the face, Leaves do not move, though drift could be noticed in the smoke plume.
ω_2	Slight Breeze	: Wind could be felt on the face, leaves rustle.
ω_3	Gentle Breeze	: Leaves and twigs in constant motion, wind extends light flags.
ω_4	Moderate Breeze	: Dust, loose paper, and small branches are moved.
ω_5	Strong Breeze	: Small trees and leaves begin to sway and/or large branches in motion and whistling from the telegraph wires could be heard.

Note: Night timings are from sunset to sunrise.

Winter conditions (in the plains) are assumed to prevail if the mean temperature (average of daily maximum and minimum temperatures) at any station persists at 20° C or below for five consecutive days. The rest of the period corresponds to summer conditions.

For the monsoon season, when the sky is clear, the same conditions as for summers are applied.

For overcast sky, cases with varying winds have been included in these scenarios.

For raining periods, clasification corresponding to overcast sky may be considered.

During foggy conditions, scenario number 21 should be considered.

During hazy conditions, scenario number 15 should be considered.

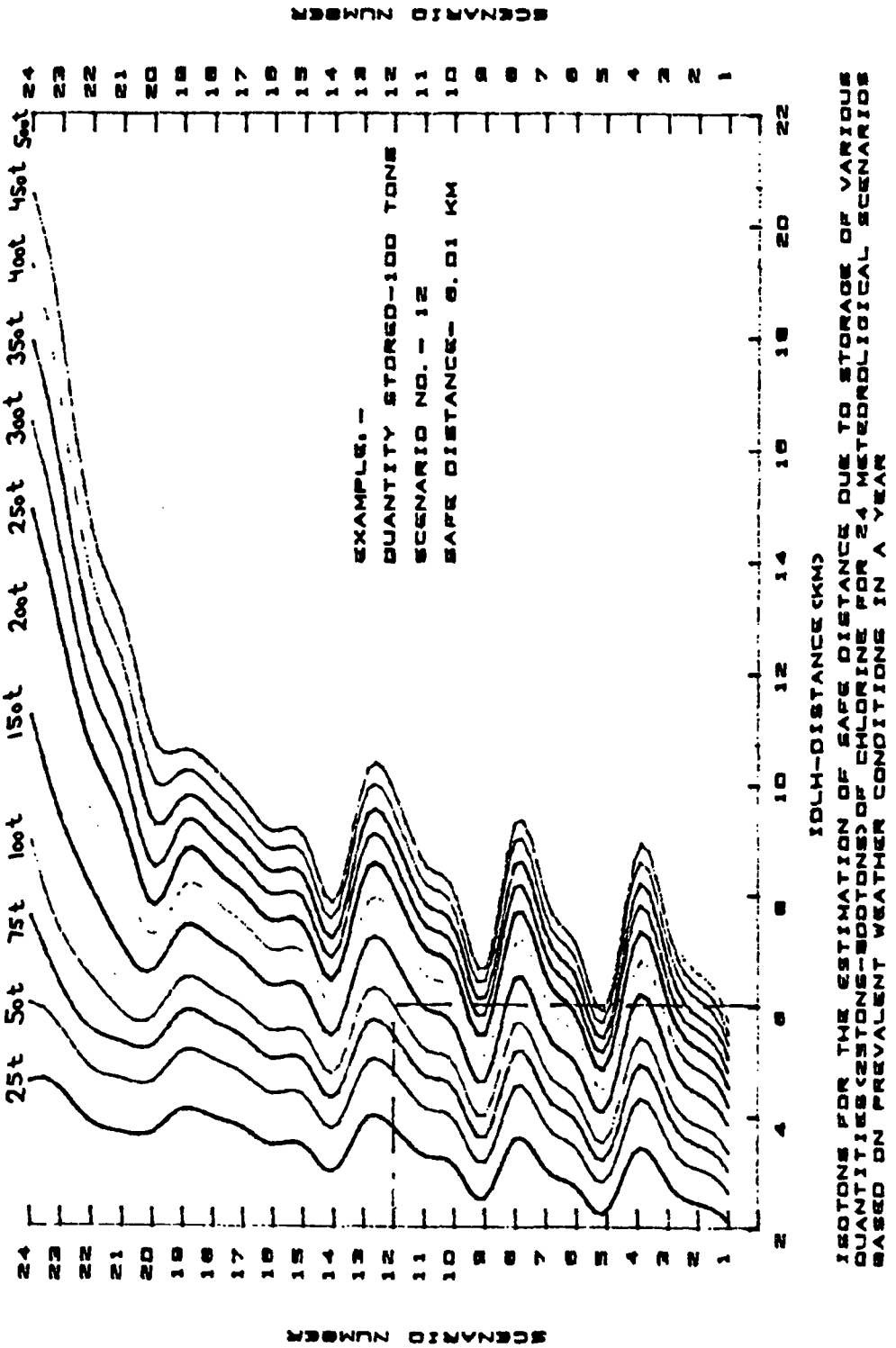
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GLOBAL INDUSTRIAL SOCIETY—VISION OR NIGHTMARE?

by

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INTRODUCTION

I was privileged to be invited to attend The Club of Rome meeting in Hannover, June 11-14, 1989, organized by the Foundation of Lower Saxony and the E. Pestel Institut fur Systemforschung in memory of Eduard Pestel, who died on Sept 19, 1988. In 1972 the very challenging report "The Limits to Growth" was published. The main conclusions reached by its authors were: "If the present growth trends in world population, industrialization, pollution, food production, and resource depletion continue unchanged, the limits to growth on this planet will be reached sometime within the next one hundred years. The most probable result will be a rather sudden and uncontrollable decline in both population and industrial capacity... ."[1]

The Club of Rome chose to concentrate its 21st meeting in Hannover on the topic of global industrialization. A number of countries, previously classified as developing, have entered the global industrialization system. Some of them have wisely based their development on widespread education and research and development (R&D). Is this global industrialization a vision or a nightmare? Certainly, economic growth in the developing countries *is a basic need and is a global concern and responsibility.*[2] However, the very assumption of global industrialization raises at least three questions:

1. Is the word *industrialization* appropriate to the reality of the present economic development of the most developed countries, based increasingly on information and services?[2]
2. What is the environmental impact of this global industrialization? For the first time man is threatening his own environment. Hitherto environmental problems have been mainly local and could be cured by local action. With the appearance of a number of global phenomena, e.g., the greenhouse effect, acid rains, thinning and ruptures in the ozone layer, and the worldwide distribution of nondegradable chemicals, environmental issues can no longer be dealt with by individual countries. In view of the environmental constraints how can the urgent needs of the Third World be met?[2] and,
3. Is the technology-based economic growth of the previously industrialized countries the unique and inevitable path to development for all countries and all cultures?[2]

These questions were discussed at the Hannover meeting. The following is my personal understanding of these deliberations, and sometimes I will add my own opinions.

THE CONTEMPORARY WORLD AND THE POSTINDUSTRIAL ERA

All major problems of the contemporary world are interconnected and mutually interdependent. Changes in a small subsystem can have profound effects on the entire system.

Though part of the world is entering a postindustrial phase, that does not mean that there is no need for industry, just as industrial revolution did not mean that agriculture is redundant. The present industrial development has also resulted in an increase in urban population. In 1950–1985 the number of people living in cities worldwide almost tripled: from 734 to 1 982 millions. It is estimated that by the year 2000 the urban population will be 3.2 billions, two-thirds of it in less-developed countries.[3,4] The city is a significant modification of the landscape, and it has even a climatic effect.[3]

The volume of the global financial market has grown and has unprecedentedly uncoupled from industrial and agricultural investment, taking advantage of the enormous indebtedness of the Third World and based on speculation as an objective in itself.[2] It was argued that market participants operate with flawed perceptions, and the flawed perceptions influence the market. Though this contradicts the prevailing wisdom that the market is always right, i.e., that in an efficient market rational expectations prevail, it correctly emphasizes that the view of participants in the market is inherently biased and that the dominant bias becomes incorporated in the outcome. As a result, the prevailing bias may appear to be justified for an extended period of time, but all the time the outcome merely serves to reinforce the bias and eventually the bias will have to be corrected. It is only when the bias eventually becomes unsustainable that prevailing expectations prove false; the rest of the time the market seems to be right.[5]

The essential elements of our comprehensive development are genetic and cultural diversity.[6] It is not only that our present form of development is endangering the genetic richness of the world. It is also—and possibly more rapidly—destroying the world's heritage of cultural diversity.

By their very nature most of the major problems of the contemporary world require political solutions. Are we capable of finding and implementing these political solutions? Are we politically mature and wise? Certainly there has been a substantial decrease in international tensions. Strong regional economic cooperations and environmental issues have been the subject at a number of recent meetings between heads of government. Nevertheless, I often wonder whether these accomplishments are done by the political leader, or in spite of them. Aren't political leaders mainly concerned with how to obtain and how to maintain personal power, even if it means creating new problems rather than solving the existing ones? An interesting paper "Can Political Leaders Tell the Truth and Still Be Leaders?" was mentioned.[7] The truth, the political truth, is certainly complex. Do political leaders know the truth? Even to the extent they know it, they behave as if the public cannot comprehend such complex matters, and leaders present only a fairly simplified version of it. The most significant progress has been achieved by rather unexpected and sudden steps toward more democracy and by science and technology. However, science and technology can be a stabilizing or a destabilizing force. For instance, nuclear weapons can cause a nuclear war. However, as emphasized already by I. Kant, peace among countries would come as a result of the increasing destructiveness of war, coupled with the spread of truly democratic government and the growth of trade. Indeed, the conventional army is more of a destabilizing force and examples in which the army is used against their own people prove that it suffocates democracy and freedom.

I strongly believe that *science is not a destabilizing force. It is our stone-age mentality—condensed in ambitions of unscrupulous politicians coupled with the destructive capabilities of intellectual evolution—that is the cause of instability.*

THE THREATS OF GLOBAL INDUSTRIALIZATION

Competition has proved to be an essential instrument of progress and prosperity, its incentives generating vitality and encouraging innovation. The negative consequences of global industrialization coupled with increased economic competition are:

- considerable waste of money, energy, natural resources, and manpower, and
- destruction of cultural identities and ethical values.[2]

The environmental impact of industrialization is complex, and it manifests itself in at least three areas:[3]

- excessive consumption of energy,
- chemical products, by-products, and waste that include compounds alien to the biosphere, and
- technological development intertwined with industry, agriculture, and transport, all of them depending on energy inputs and producing pollution.

Energy has become an essentially political issue. Prior to the discovery and development of fossil fuels, wood was the principal source of energy. Even today, two-thirds of the Third World countries depend on wood for their household energy needs, e.g., Malawi (93%), Kenya (71%), and Nigeria (82%).[8] This is one of the causes of worldwide deforestation in the tropics. The FAO estimated that 11 million hectares are cleared annually, and only 1 million are planted. [9] The forest has its role in environmental balance: soil conservation, hydrology and carbon cycle. Clearance of forests reduces the capacity of a principal sink of carbon dioxide. Fossil fuels have become the principal source of energy consumed worldwide. Energy consumption is likely to keep increasing throughout the first half of the 21st century. Fossil fuels give rise to CO_2, SO_x, NO_x, etc.; natural gas is a cleaner fuel and coal is the greatest polluter. At present, about 90% of mankind's industrial energy comes from fossil fuel. The measured amount of CO_2 in the atmosphere increases exponentially at a rate of 0.2% per year. Per-capita energy consumption in the world was, in 1970, increasing at the rate of about 1.3% per year, which, including population growth, means a total increase of 3.4%. These were the conclusions stated in "The Limits to Growth" in 1972.

We now try to answer whether these growth trends have actually taken place and which trends should be feared during the next 15 years.[10]

The exponential trends of "The Limits" imply that in 1987, compared to 1972, per-capita energy consumption would have increased by 21%, total energy consumption by 65%, and atmospheric CO_2 concentration by 3%. In reality, total energy consumption increased by 46%. This is partly because the world population did not grow at 2.1% per year, but at 1.9%. The main reason is the lower per-capita consumption, which is related to a slower economic growth and an improved energy efficiency in the industrialized countries. However, the atmospheric concentration of CO_2 increased at the rate of 0.3% per year, i.e., 67% more than feared by "The Limits"!! This points to a declining CO_2 absorption capacity due to deforestation and ocean pollution. The global mean temperature has increased 0.3-0.7°C over the last 100 years. This increase could be due to natural factors, but there are reasons to believe that it is at least partly due to man. The effects of global warming might be quite serious: regional climatic changes making presently fertile regions unproductive and causing a sea-level rise of 40-140 cm. A WHO-UNEP-ICSU conference in Villach, Austria in 1985 concluded that, if present trends continue, the concentration of greenhouse gases will be doubled as early as 2030 and could lead to a rise in global temperature of 1.5 to 4.5°C. Combinations of SO_x and NO_x form acid rain, which acidifies lakes and rivers and causes the

massive deaths of forests —"Waldsterben." Complete mortality of vegetation was reported in an inner zone of 2000 km^2 surrounding the Incometal smelter in Sudbury, Ontario.[11]

The world conference on the changing atmosphere was held in Toronto in June 1988 and more than 300 scientists and politicians participated. It was decided that by the year 2005 the emission of CO_2 should be reduced by 20% from its 1988 level. In the US Congress, two even more ambitious bills have been introduced in 1988. They aim at reaching a 20% reduction in the year 2000. Such aims are not easy to achieve. They require massive R&D and global political thinking and actions. To reduce global CO_2 emission implies that the use of coal as an energy source would practically have to end in less than 30 years (in spite of world reserves of at least a few hundred years) and of oil in about 50 years. It is clear that this will have dramatic local effects, e.g., the port of Rotterdam will have to find a different use, since now over 50% of its tonnage is oil and coal. Industry produces, among other things, some 70 000–80 000 chemicals that go to the market and eventually in the biosphere. At least 1 000 to 2 000 new chemicals enter the market each year. Industry generates about 350 million tons of hazardous wastes per year and there is a disturbingly large number of industrial accidents, e.g., during 1980 to 1985, there were almost 7 000 industrial accidents in the US, an average of 5 a day.[4] Rapid industrialization of presently underdeveloped countries justly raises the question of whether the safety standards in these areas will be as good as in developed countries. Even if safety requirements are high, global industrialization will produce simply more chemicals and more waste. Chlorofluorocarbons have perhaps affected the ozone layer. The depletion of stratospheric ozone has become one of the major global environmental problems.

EVOLUTION AND THE REVERSAL OF VALUES

The world evolves toward greater, hierarchically structured, complexity. Although the formation of atomic nuclei inside the stars indispensably requires high temperatures, these high temperatures are absolutely destructive for further evolution as soon as atoms are formed. Thus, what has been a positive value becomes negative. During the course of evolution we can find many such examples. The geophysical environment filled by ultraviolet light, electric discharges, and volcanic activities, all of which served as a cradle for the formation of life, becomes fatal to any living being. Another example of value reversal occurs at the time when multicellular organisms develop. Whereas the unicellular organism has only one dream—to become two cells as soon as possible, since this is its best guarantee for future existence—such behavior is fatal for multicellular organisms. If a cell reverts to the behavior of its unicellar ancestors, it is a cancer cell. The development of the central nervous system introduced, in addition to a genetically encoded information system, an intellectual information system. The rigid genetic mechanism becomes inadequate and could be a handicap for the species when environmental conditions are changed. The appearance of man occurs as a consequence of a shift in the selection from individual to small blood-related groups. Individual rivalry is at that time replaced by group morals. The fast development of science and technology has introduced an intellectual evolution. These are fundamental changes paralleled only by those of four billion years ago when physical evolution was overcome by biological evolution. As soon as biological evolution started, it overtook physical evolution. It was simply much faster.

Similarly, when man's socioeconomic technology takes over, biological evolution must end. Man has taken upon himself complete responsibility over the planet where he lives (though we might not be fully aware of this fact?!). Virtually all the trees in the Black Forest today are planted by man. What animals will survive the next few hundred years is predominantly our decision. Global problems are now dominant. Group ideology is an old value system that the future of evolution requires to be reversed. The role of a

leader who tries to homogenize an entire group becomes drastically changed in the new morality with global emphasis. Indeed, the concept of a classical leader might be disappearing. The very word leader might have derogatory connotations and, in at least two languages, it indeed has derogatory meaning: Führer and Duce.

In that context, the questions of whether war is too important to be left to generals and whether peace and development are too important to be left to political leaders become irrelevant. Obviously, significant progress has to be achieved in our political thinking. There is no doubt that our true strength is in our five-billion brains and the multiplicity of cultures. It is their free, democratic political thoughts and actions that can best find solutions to many problems we face today. No leader, no matter how clever and wise, could do it. It is necessary that we move increasingly toward democracy. Not only must different thoughts be tolerated and allowed to develop, even when the majority is opposed to them, but we must create conditions that will enable the realization of what I call Galileo's goal: that the humble reasoning of a single man could prevail over the authority of thousands. This goal is sometimes realized in science, but in politics it has appeared only in its malignant alteration of dictatorship.

OMEGA PLAN

The present differences in development among various countries and regions are simply no longer globally acceptable. Development of presently underdeveloped nations is a global concern. This has been the subject of numerous analyses and experts agree that the approach is the therapeutics of complexity. What does it mean? It is obviously wrong to develop through emphasizing heavy industry. Experiences of many socialist countries have shown the failure of such approaches. However, it is also unacceptable to try to implement in these developing countries a model of present western countries for at least three reasons:[13] 1) this model is incompatible with the diversity of the cultures, 2) it has many defects, and the main objection is that it cannot be extended to the entire world, and 3) it is itself in constant change and we do not even know how to define it.

The essential thing is to trigger a process of a true endogenous development—one that is specific to the given physical, biological and cultural environment. It is necessary to work out an extensive set of development operations that would fit into existing environments. This program is called Omega,[13] in reference to the supreme convergence of Teilhard de Chardin. Since, in all cultures, people are concerned with basic questions of existence, it seems that fundamental science is the best avenue for stimulating development. Today, the Third World is only slowly waking up to the realization that, in the final analysis, creation, mastery, and utilization of modern science and technology is basically what distinguished the South from the North. And I quote the October 1988 Trieste declaration:[14]

"The members of the Third World Network of Scientific Organizations resolve to work towards giving science and technology the highest position in their countries." The development of science in the Third World countries is not only in the interest of these countries, it is also essential for the development of science. Namely, future development of science crucially depends on manpower, and the R&D manpower potential of highly industrial countries cannot be increased by more than 25 to 30%. Underdeveloped countries have talented potential researchers. Science has used these talents in a rather wasteful way.

There is much discussion of a Marshall plan for Eastern Europe and for developing countries. The Marshall plan is not directly transposable to any other than its own situation. The Omega plan has to be a good business for the supplier, who provides knowledge, technology, and organization. It seems to me that

the establishment of major international research centers in judiciously chosen countries, either in the Third World or among what is called peripheral countries, is one systematic way to initiate such Omega plans.

CONCLUSION

In the press release of the Hannover conference it is stressed that "...man is—for the first time—threatening his own environment. The most imminent of these dangers is the probable heating of the surface of the Earth, with a greater effect at high latitudes than at the equator, changing the thermal currents of the world, patterns of rainfall, and hence of agriculture. It is expected that the level of the seas will increasingly threaten low-lying areas. The effect is caused by the burning of fossil fuels and by deforestation... . A global strategy is indipensable."

It is imperative to act urgently and the meeting proposed the following actions:

- a worldwide campaign for energy conservation and efficiency;
- the replacement of oil and coal by gas whenever possible;
- reforestation; and
- high priorities on R&D, in particular on alternative energy sources and on the genetic engineering of grains to enable them to withstand wider environmental variations.

Agriculture has become energy-intensive, and it excessively uses fertilizers, pesticides, and weed-killers, all of which in turn produce high pollution. The Club of Rome suggests that governments, NGOs, educators, scientists, industrialists, trade-unions, etc., should mobilize to respond to the imminent need to institute comprehensive preventive measures. At least two ways should be used: dialogue and education.[2]

The Club of Rome calls for:

- A North-South Conference on environmental imperatives, which should lead to the creation of a UN Environmental Security Council;
- Regular meetings of a—to be constituted—"Cooperation Global Development Round" (CGD Round) of industrial leaders, bankers, and governments, in the light of environmental constraints;
- A new approach of global industrialization integrated into educational programmes with new priorities, namely, working conditions and the quality of life, the protection of the environment, energy and resource saving through Ministers of Education, schools, educational bodies, parent associations, TV programmes;
- A special working group with the UNEP, UNESCO, and educators to elaborate a teaching programme and an information campaign on what should be done at different levels, including that of the individual.[2]

Comprehensive development, global industrialization, and its effect on our environment are certainly basic problems currently facing mankind. Besides the Club of Rome, several other prestigious associations, e.g., Council of Academies of Engineering and Technological Sciences of the USA,[15] IFIAS (which was to my knowledge, the first international body to call attention to the greenhouse effect), and Academia Europaea[16] have also discussed these problems, reaching essentially the same conclusions.

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US-SOVIET COLLABORATION IN ENERGY-CONSERVATION RESEARCH AND DEVELOPMENT

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ABSTRACT

A U.S.-Soviet collaboration in energy-conservation research and development, begun five years ago, has had considerable impact in both countries by identifying options in the energy system that can reduce adverse impacts on global climate and stresses in global energy markets. Highlights of the collaboration are reviewed, with particular attention to the component of the collaboration involving joint field experiments in energy efficiency in large apartment buildings. Arguments are set forth for the importance of obtaining the active participation of the Soviet research community in the formulation of strategies to develop an environmentally sensitive global energy policy. Going beyond the current collaboration, an Environmental Action Corps is proposed, focusing on targeted assistance to developing countries for the purpose of reducing adverse impacts on the global environment. The Environmental Action Corps could be either a unilateral U.S. initiative or a coordinated multinational effort that might include the Soviet Union. In the latter case, the consultative processes already in place in the current collaboration in energy efficiency may be of use.

OVERVIEW OF THE COLLABORATION

For the past five years Soviet and American researchers have been working together on collaborative projects related to energy efficiency. One of the principal motivations on both sides for this collaboration has been to accelerate the rate at which each country learns to implement energy strategies that reduce the stresses on global climate and on world oil markets.

The Soviet Union and the United States are the two countries of the world that transfer the largest quantity of carbon to the atmosphere from fossil fuel each year. In 1985 the Soviet Union transferred approximately 1.0 billion metric tons of carbon per year and the United States transferred approximately 1.3 billion metric tons per year, between them accounting for about 45 percent of the total world transfer associated with fossil-fuel use.[1] Moreover, as current and future energy producers, both countries play major roles, each having globally significant (and, from the point of view of the earth as a greenhouse, troublesome) coal reserves, the Soviet Union having an extremely important gas reserve, and the United States having additional leadership responsibilities inherent in its technological and financial prowess.

The Soviet-U.S. collaboration in energy-conservation research and development was conceived by Academician Evgeniy P. Velikhov during a visit to Princeton University in November 1983. At Princeton Velikhov was given a private briefing on the "end-use approach" to energy policy analysis, as practiced in

* An earlier version of this paper will appear in the Proceedings of IEA/OECD Expert Seminar on Energy Technologies to Reduce Emissions of Greenhouse Gases, Paris, France, April 12-14, 1989.

the West. The end-use approach begins with the question of what energy is used for (space heating, lighting, transportation, steelmaking, etc.) and proceeds to examine alternative technologies (infrared-reflecting window coatings, variable-frequency motor drives) and associated policies (vehicle fuel-economy standards, building codes) that might permit these end uses to be provided with greater energy efficiency. Velikhov quickly grasped that the research community in the Soviet Union had "missed an important component of the energy debate." He expressed a desire to inject such end-use analysis into Soviet energy research and proposed a U.S.-Soviet collaboration as the principal mechanism to begin this task.

Five years later it would be right to include in what the Soviets call "new thinking" an energy-policy analysis that addresses in a balanced way both end-use efficiency and efficiency in energy production. "Old thinking" (to be sure, practiced still not only in the Soviet Union!) considers the technical details of the demand for energy not to be part of the responsibility of the energy researcher, who instead is to give his or her exclusive attention to the problem of assuring "adequate" supply. One of the most important lessons to be derived from this collaboration is that working side by side on common projects leads to fundamental changes in perceptions.

Thus far, the actual collaboration has taken the form of a series of symposia and workshops alternating between the two countries, during which progress in each of several research areas is reviewed and next steps are planned. The first symposium was held in Moscow in June 1985; its proceedings have been published as a special double issue of *Energy: the International Journal.*[2] The second and third symposia were held in August 1986 in Wingspread, Wisconsin, and in October 1988 in Yalta, Ukrainian Republic, respectively. The program is being conducted within a cooperative agreement between the U.S.-National Academy of Sciences and the Soviet Academy of Sciences.

As described in detail in the memorandum signed at the conclusion of the Yalta meeting, the collaboration is currently formulated around seven Project Areas:

1. energy-conserving electric systems and devices,
2. advanced integrated energy technologies,
3. energy conservation in buildings and its influence on the indoor environment,
4. conservation of energy in industry,
5. macroeconomic analysis of trends in energy consumption and strategies for energy conservation,
6. renewable energy sources, and
7. regional least-cost energy planning.

It should be apparent from this list that the collaboration has broadened from its original end-use focus: only areas 3 and 4 are concerned principally with end use. In fact, all seven areas involve the sometimes subtle interplay of end-use and production.

In December 1988 the scope of cooperative research between the Soviet Academy of Sciences and the U.S.-National Academy of Sciences was substantially broadened as the result of discussions between delegations from the two academies in Irvine, California. A new interacademy standing committee on global ecology was established, as well as a new theme for cooperation: "Global Energy Development and Associated Ecological Problems." Within such a framework, entirely new projects related to climate and energy should emerge.

TYPOLOGY FOR COLLABORATIVE PROJECTS

The characteristics of any international collaborative project evolve as participants get to know the details of one another's interests and experiences. Indeed, one can write down a typology for the stages of collaboration:

Stage 1. Sharing information and becoming familiar with one another's specialized vocabularies and modes of thinking.

Stage 2. Preparing joint papers or books.

Stage 3. Performing joint experiments in the lab or in the field.

Stage 4. Becoming involved jointly in the implementation of actions that express the consequences of the project, such as new regulatory policies for the governments of the participating countries.

Stage 5. Broadening the scope of the collaboration to include participants from additional countries and those countries' concerns.

Such a progression ought to be in the minds of anyone who designs or participates in international collaborations. The later stages cannot be realized productively without first passing through the earlier ones. The joint production of new knowledge, even knowledge of a highly specialized character, is the best kind of shared experience on which to build mutual understanding and trust. Such understanding and trust, in turn, is a prerequisite for the creation of coordinated and effective national policies addressing global environmental problems.

In the next section of this paper I will describe in some detail a particular collaboration within the cooperative research on energy-conservation research and development. The collaboration is now at stage 3, with stage 4 in view. In addition to conveying a sense of an intrinsically interesting activity, this description is intended to illustrate the progression by stages just presented above.

EXAMPLE OF WORK IN PROGRESS: ENERGY-CONSERVATION OPPORTUNITIES IN LARGE APARTMENT BUILDINGS

The most vigorous collaboration at this time is in area 3, "Energy conservation in buildings." Our Soviet collaborators work at the Scientific Research Institute for Building Physics (NIISF), Moscow, and at the Scientific Research Institute of GOSSTROY, Estonian SSR; these institutions have lead responsibility at the national and republic level, respectively, for the technical investigations that support building standards. The American researchers, as befits a much more decentralized society, come from a larger cross-section of institutions: Massachusetts Institute of Technology, the University of Illinois, the University of Minnesota, Princeton University, the Natural Resources Defense Council, the Northwest Power Planning Council, and Oak Ridge National Laboratory.

The most exciting collaboration under way within this project area at this time is a field study of energy-conservation opportunities in Lasnamae, a complex of residential high-rise buildings in Tallinn, Estonia. This project has several objectives:

1. Engage the Soviet energy research community in studies of actual (as opposed to presumptive) energy consumption in buildings, a challenge necessitating measurements in the field. Like most of their counterparts in the West, Soviet buildings researchers have concentrated, through most of their careers, on

mathematical modeling and laboratory studies. There has been no sanction for studies of the much messier but ultimately much more crucial issues of actual building performance after construction and with real human beings inside.

2. Engage the Soviet energy research community in studies of the large residential "blocs" in which such a large fraction of Soviets live. These buildings may turn out to offer opportunities for cost-effective energy conservation just as significant—from the perspectives of global climate and pressures on world oil markets—as those opportunities represented by the American automobile in the 1960s.

3. Jointly confront the issue of apartment-level control of indoor temperature. Preliminary indications suggest that the large Soviet residential buildings suffer from many of the principal energy-wasteful features of large residential buildings worldwide, including—as probably the single most energy-wasteful feature—the absence of apartment-level control of interior temperature, leading to a situation in which the principal method of interior temperature regulation is the opening of windows, even in the coldest weather. The relatively new technology of thermostated radiator valves, rarely deployed either in the Soviet Union or in the United States at this time, would appear to offer considerable promise.

4. Develop the instrumentation and the software necessary to obtain usefully normalized data on energy consumption for space heating in large residential buildings. One useful measure, for example, would be cubic meters of gas per year per square meter of floor area per heating degree day. A refinement, using software known as PRISM,[3] would permit the separation of energy use into a weather-dependent and a weather-independent portion. Such measures are virtually unobtainable today for the large building complexes of the Soviet Union, in part because few buildings or building complexes are metered for space-heating energy consumption. Such data will be necessary both to compare buildings with one another and to compare performance in a single building over time.

5. Gain experience with advanced energy-conserving building technologies. In this instance, with the guidance of the Natural Resources Defense Council, the Soviets are about to experiment with low-emissivity window coatings, coordinating both laboratory and field studies. The disciplining effect of merely contemplating field tests of such advanced windows has made salient to all concerned that the potentially substantial energy savings associated with reductions of heat losses through closed windows will be nearly exactly compensated by increases in energy waste through open windows—if the amount of heat supplied to the building cannot be reduced, a situation that will arise in the absence of controls on the heat supply that are responsive to interior temperatures.

There is an additional, more unusual feature of the Lasnamae residential community, one which opens up possibilities for in-depth studies of the potential for cogeneration as an energy-conservation strategy. Remarkably, the community is in a nearly one-to-one relationship with the thermal load of a single nearby power plant: the building space heating and water heating are almost the only thermal loads served by the plant, and no other energy sources provide the space and water heating. It is conceivable, in such a system, for the overall effect of reduced energy consumption at the building complex to be merely the dumping of all of the saved thermal energy into the local environment (air and water) right at the power plant, with no fuel savings—or reductions in carbon emissions to the atmosphere—whatsoever. Only a coordinated approach that combines energy-saving strategies in the buildings and changes in operating procedures at the power plant will have the desired effect on world fuel use.

It may be feasible within the collaboration to conduct actual experiments on alternative modes of operating the power plant and the residential building controls (including explorations of the potential for thermal storage in the buildings), a class of studies that would certainly be first-of-a-kind. Thus, the ecological principle that everything is connected to everything else is reaffirmed in this collaboration, as

we move from the introduction of the radiator valve (in area 3), to the operation of a cogenerating electric power plant (in area 2), to the fuel-use and pricing policies of major countries (in area 5), and to the implementation of policies to disseminate energy-conserving innovations (in area 7).

FURTHER ARGUMENTS FOR STRONGLY ENCOURAGING SOVIET PARTICIPATION IN THE DESIGN OF A MORE ENVIRONMENTALLY SENSITIVE INTERNATIONAL ENERGY POLICY

The principal arguments for obtaining the participation of the Soviet Union in discussions of an environmentally sensitive international energy policy have already been presented: their energy consumption is large, their opportunities for energy conservation are large (among other reasons, because their economy has incorporated substantial subsidies of the prices of energy for many decades), and their energy resources are large. But in addition to these reasons, two others should be noted:

1. The Soviet Union has a large work force, especially in engineering, available in principle to address technical aspects of global environmental policy. In some areas related to energy conservation, Soviet research is as good as research anywhere in the world, for example, in electric machinery, gas turbines for stationary power, and economic modeling. (The U.S.-Soviet collaboration has zeroed in on precisely these topics, on the grounds that they offer the greatest potential to demonstrate short-term results.) But more important than the current level of effort or the quality of current work is the potential for rapid scale-up that is latent in the Soviet Union's very large, technically trained labor force, coupled to a governmental structure in which the discipline of engineering is dominant. In any one of numerous areas bearing on the challenge to global climate, the Soviet Union could (say, in five years) launch a research-and-development effort of great interest.

2. The Soviet Union, to a greater extent than the West, invests in large test facilities and pilot facilities as an integral part of the process of technology development. Moreover, these facilities have a history of falling far short of their potential, for want of modern diagnostic equipment and modern data processing. There would appear to be a broad class of mutually advantageous collaborations based on these differential capabilities. Among the projects identified in our collaboration are test facilities for the integration of large photovoltaic arrays into electric grids, multi-fuel-capable gasifier testing facilities linked to advanced diagnostics to study the size and chemical composition of residual particulates, and flexible gas-turbine test facilities designed to assess residual gaseous emissions as a function of cycle modifications including steam and water injection. In the latter case, Soviet researchers have urged that early attention be paid to the possibility that nitrous oxide (N_2O), an important greenhouse gas, may be produced in increased quantities as an unintended side effect of some ammonia-based control strategies for the better known nitrogen oxides (NO and NO_2) of significance in acid precipitation—thereby exchanging a regional environmental problem for a global one![5] The path is certainly not fully clear that would lead to the integration of policy-making and research in the Soviet Union and into a concerted global strategy for moderating the fluctuations in world energy prices and reducing the adverse effects of people on climate. Considerable creativity is still needed. But the experience of this collaboration suggests that such an integration is not overwhelmingly difficult and its payoffs are of many kinds. The most important ingredient for success is a willingness to try.

NEXT STEPS: A U.S. ENVIRONMENTAL ACTION CORPS AND ITS COUNTERPARTS IN OTHER INDUSTRIALIZED COUNTRIES

The atmospheric greenhouse problem is the archetype for a new class of problems that are appropriately attacked only at a planetary scale. When the challenge is to find a set of energy policies that balance the interests of separate regions of the U.S., the U.S. can do its policymaking in relative isolation—even doing its bookkeeping in quads, an energy unit used nowhere else in the world. When the challenge is to respond to assaults from an oil cartel on the independence of foreign policy, national energy planning is no longer adequate, and alliance-level planning (expressed, for example, in the International Energy Agency) becomes appropriate: the bookkeeping shifts to volume per day of oil (or oil equivalent) traded. But when the challenge is to reduce the pace at which human beings produce stress on global climate, even alliance-level planning is inadequate. The bookkeeping is now in rates of transfer of carbon from the surface and subsurface of the earth to the atmosphere as a result of human activity (currently, about seven billion tons per year). The whole global community becomes involved.

Virtually no institutions exist at present that have as their purpose the transfer of skills and technologies addressing global environmental objectives. This essay has described some first fledgling efforts to institutionalize such transfers between the industrialized market economies and the industrialized centrally planned economies. It is clear, however, that there is another, even harder task straight ahead in the road—the task of providing mechanisms for the two-way transfer of skills and technologies between industrialized countries of all kinds (the so-called North) and the developing countries (the so-called South).

Successful institutional inventions combine elements of self-interest and elements of altruism. With lend-lease during World War II, the U.S. found ways of helping its allies defend themselves against the Axis powers and at the same time reduced the scale of U.S. casualties. With the Marshall Plan the U.S. strengthened its alliance against the Communist bloc, and it also helped in the economic recovery of war-ravaged Europe.

The Peace Corps has been a success because it has combined the satisfaction of helping the least prosperous people on earth and the national self-interest in having a political presence in societies engaged in ridding themselves of colonialism. What is needed to make headway with global environmental problems are institutions that harness the idealism of helping others and the self-interest in optimizing the national investment of dollars and talent in achieving global-scale environmental improvement.

It makes sense, from the point of view of the rational economic planner adopting a planetary perspective, for the U.S. not to invest at the margin exclusively in strenuous domestic belt-tightening if there are U.S. investments abroad that achieve the same degree of environmental improvement at less cost. Implicit in this essay is the proposition that there may well be numerous investments in the Soviet Union that U.S. investments could trigger and that would be more productive of reductions in carbon-dioxide emissions per dollar than many investments in the United States domestic economy having the same objective. This sort of argument may be even more persuasive in the case of investments in developing countries. A new national institution analogous to the Peace Corps, but focusing specifically on targets like energy efficiency, forest management, and other environmentally responsive strategies, would therefore seem expressive of the objective of economic optimization. Tentatively, let us call this institution the Environmental Action Corps.

Should such an Environmental Action Corps be developed by an individual industrialized country, rather than as a multinational institution? Probably, yes. The development of new institutions is a sufficiently daunting task that one should probably construct an Environmental Action Corps in each industrialized

country independently and, moreover, work out the sensitive details of the relationship with any particular developing country one country at a time through bilateral discussions. The alternative, for example, in which a multinational enterprise would negotiate with several recipient countries at once, does not seem consistent with the way the world is currently arranged. But, surely, the respective national Environmental Action Corps of several countries could be developed in parallel, and their actions could be coordinated, at least loosely.

In particular, there is no obvious reason why the United States and the Soviet Union could not be among the first countries to launch an Environmental Action Corps. In that case, the consultative processes already in place in the current collaboration in energy efficiency may be of use. Invoking the typology of collaboration discussed above, the collaboration would evolve to stage 5.

It is crucial, once again, to act boldly—in response to qualitatively new challenges. I would like to see the United States launch an Environmental Action Corps early in the Bush administration. I would not want the latent potential of coordinated efforts in several industrialized countries to hold back the launching of such an effort. If such coordination can be used as a spur to getting started, however, so much the better.

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A JOURNALIST'S PERSPECTIVE: LESSONS OF THE JOINT VERIFICATION EXPERIMENT

by

Lawrence Spohn
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Nearly one year ago, the globe's nuclear heavyweights squared off, in the desert of Nevada; not in confrontation, but to conduct a remarkable cooperative test called the "Joint Verification Experiment." In short, the JVE.

The initial objective was to affirm two outstanding, but unconfirmed, US-Soviet nuclear test limitation treaties: The 1974 Threshold Test Ban Treaty and the 1976 Peaceful Nuclear Explosions Treaty. They limit underground nuclear explosions to not more than 150 kilotons. While both nations say they have observed this limit, neither treaty was ever formally ratified or enforced. The hang-up had been verification: Our government didn't trust theirs and later theirs didn't trust ours. Both wanted assurances that they could catch the other guy cheating. The Soviets have contended that distant seismographic techniques were adequate for the task; the US has insisted upon on-site verification.

Enter the JVE, the particulars for which were worked out in May 1988, barely six months after the two countries agreed to reopen negotiations on the two outstanding treaties. By agreement each country would explode one of their nuclear bombs underground at their most secret nuclear proving grounds: First, at the United States Nevada test site (NTS), on August 17; and a month later, September 14, at the Soviet Union's Poligon, near Semipalatinski.

I was among the journalists who covered the JVE, but I should tell you at this point that despite my best efforts and the typical last-minute Visa from the Soviet Government, I did not make it to Poligon. As has been noted by other presenters at this conference, I too was a victim of bureaucracy which stranded me in Moscow. In my case, misinformation from the Soviet Embassy, got me to Moscow hours after the one and only flight had departed for Semipalatinsk. Several officials, Soviet and American, worked on my behalf, but it apparently would have required truly extraordinary measures to arrange transport to the test site some 1 800 miles southwest of Moscow.

In the JVE, the bombs themselves apparently were routine, but these explosions were unique because each nuclear superpower, for the first time, permitted its adversary to have on-site observers. Indeed, we were told, it was the first time in Soviet nuclear history that **any** non-Soviet citizen had been permitted at Poligon.

More importantly, the JVE allowed each country to use its own on-site verification monitoring equipment to independently determine the explosive yield, or power, of each bomb. The Americans used Corrtex, the "Smart Little Box," a sophisticated computerized, on-site hydrodynamic yield detector. The Soviets employed their equally advanced system, called Miz. And, as we were told, both lived up to expectations. Although the results still have not been officially released, the two detectors apparently were remarkably consistent with each other and the known yields. The yields, of course, were kept secret by each country prior to detonation. They compared data afterwards; but, by JVE agreement, the data could not be released publicly unless both sides agreed to it. Makes you wonder who the real adversary is? Soviet Academician Yevgeny Velikov laughed in telling me, "It's big secret between American and Soviet military."

At any rate, by all accounts, each half of the experiment was a smashing success, literally. Not only did the verification systems produce the data necessary, but they also generated highly optimistic official

statements. The events themselves, and the processes required to make them successful—that is a high degree of US-Soviet diplomatic, scientific and engineering cooperation—seemed to create a genuine, if restrained, camaraderie. From what I gathered, that was especially true among the scientists of the two countries who had to work closely together.

Soviet scientists were enthusiastic in their evaluation of their colleagues, as were the Americans of their counterparts. The Soviet technical team leader, Viktor N. Mikhailov, said he believed the test had etched a Soviet window into the hearts of Americans. Don Eilers, technical chief of the American team said he hoped that window was "transparent" showing that "we Americans are a warm, sensitive and compassionate people."

Each group seemed to enjoy sharing—and perhaps showing off a bit after all these years of secrecy—their particular way of doing it.

The United States had to fly a special drilling rig to the Soviet site, because US scientists were not confident about Soviet abilities to drill a straight hole, precisely parallel to the ground-zero hole, to house the corrtex detector cables. Conversely, American observers at the Soviet test site were shocked to find themselves a scant 2 miles from ground zero, in the open, standing or sitting on bleachers. The Soviet test site commander, General A.D. Ilyenko, reportedly told the somewhat apprehensive American diplomats and scientists that he had become quite proficient at estimating a nuclear bomb's yield—by how far his boot heels left the ground.

"Better than Corrtex," they quoted him as saying. He claimed his boots were accurate within 10 percent of the actual yield. Corrtex, the experts touted, was good within 30 percent.

In contrast, the scene at the Nevada test site was quite subdued. There—where we were told safety is job one—observers were seated in a plush, though crowed, concrete bunker control room. It was 30 miles from ground zero, and only the most intent among us felt the ground move.

Spontaneous applause greeted both detonations, and their historical context was lost on no one. Indeed, American workers at Poligon got caught trying to smuggle out a piece of the Russian motherland—and a particularly prized piece at that. The Soviets were more reserved. They so treasured bits of Americana that Poligon reportedly resembled a Las Vegas casino. Among the treasured capitalist trinkets was a key ring from Nevada's notorious Mustang Ranch.

The JVE was full of ironies, not the least of which was the official swearing-in, at Poligon, of the United State's top nuclear honcho. In the realm of "Believe it or Not," Joseph Salgado actually was sworn in as Deputy Undersecretary for Nuclear Weapons at the place where the Soviet Union for decades had proved its nuclear warheads, weapons aimed at American cities. This event occurred after American officials learned Salgado finally had been confirmed by the Senate and they simply couldn't let the irony slip by. "Another first," chuckled US Arms Control Ambassador C. Paul Robinson, who said the quiet ceremony had included the Soviet top brass at the test site.

Officials at the Nevada test site had had the opportunity to get commemorative T-shirts and baseball caps, although we understand some blue collar workers there were in a tizzy over the Soviet flag flying over the site. Soviet authorities, including some three-star generals, "prized" the American delegation's lapel pins, which crossed the stars and stripes with the sickle and hammer. In return, Soviet officials commemorated the event by distributing no less than aerial photographs of ground zero at Poligon.

Clearly, the most dedicated of the cold warriors had come in from the cold, and they were warming themselves at each other's fires. Afterwards in an interview in Moscow's Rossija Hotel overlooking the

Kremlin, Ambassador Robinson, Chief of the US negotiating team and former Director of Nuclear Weapons Programs at Los Alamos, observed that the "doing" of the JVE was proving as important as the outcome.

"We have come quite a ways," he said. "For four months we have been living at each others' test sites. It has been a real period of trust and of confidence building. I think that is as important a story as the verification experiment itself." A month earlier, at the Nevada test site, Los Alamos National Laboratory Director Sig Hecker said, "It was more than just a unique technological experiment, it was a successful social experiment."

Yet despite all this good will and optimism, here we are ten months after detonation at Poligon, eleven months since the sister explosion at the NTS, without either of the outstanding treaties ratified. Representatives of the nuclear giants sit in Geneva trying to work out a verification protocol that will permit each country's leadership to once again endorse the decade-old treaties. Indeed, the United States, at last report, still opposes releasing the official yields of the two blasts. These data, some geologists and environmentalists insist, will support the contention that seismographic verification techniques are about as accurate as Corrtex or Miz in determining underground bomb yields.

Leading scientists at Los Alamos, where Corrtex was developed, hotly dispute that. They insist that, until there is a greater data base for comparing and calibrating the seismic observations with actual on-site yield figures, the on-site verification technology is essential for their confidence. They also warn that seismographic observation is highly subject to "spoofing."

Yet, even some of these "best-technology" verification advocates are puzzled by the US penchant for secrecy in the matter, that is, the refusal to release the JVE data.

The Geneva stalemate was predicted by Soviet physicist Yevgeny Velikov, science advisor to Mikhail Gorbachev and Vice President of the USSR Academy of Sciences. Only days after the blast at Poligon, Velikov said in an interview at the Academy that the JVE was "a political game" that the Reagan Administration was truly not interested in either enforcing the existing test ban nor in beginning talks for a Comprehensive Test Ban Treaty. Scientists and negotiators on both sides had touted that possibility during the JVE process.

Some American observers, however, suggested Velikov was among the best players of that game. They suggested that Ambassador Robinson was not blowing smoke when he said in Moscow that he wanted the treaties ready for signing before President Reagan left office. And shunned Soviet scientists and refuseniks, seeking a way out, warned that the United States should not be lulled to sleep by the recent Soviet reforms.

Cynics observed nearly a year later that it all just amounts to bad timing. The Soviets, looking to the US election, were not particularly anxious to conclude the negotiations. Now that the Soviets are ready, reportedly the Bush Administration is trying to get up to speed. There are some unofficial and unconfirmed reports that the Administration is even toying with the idea of reopening the test ban treaties themselves, instead of focusing narrowly on the verification issue.

Finally, in terms of this conference, it is worth emphasizing that the seismographic experiments, allowed but conducted independently of the two governments, were organized by an environmental group, the Natural Resources Defense Council (NRDC), in Washington, D.C. US and Soviet geologists set up observation stations in a rough circle around the other's national test site. Although it is impossible to say for certain until the official JVE data are released, supposedly leaked information about the US test suggested a fairly close agreement with official Corrtex data.

Most recently, the NRDC also has been working with the Soviet Academy of Sciences—but without US blessing—on detecting armed nuclear cruise missiles. That verification experiment is being conducted aboard Soviet ships in the Black Sea.

It may be that national or international environmental groups and organizations could themselves be a global resource. Pursing a non-confrontational though special interest agenda, they may form international bridges across which governments might fashion cooperative global environmental, energy, and arms control accords.

Finally, from my limited experience and contacts, it was clear that the people of both the United States and the Soviet Union saw considerable promise in the JVE. Scientists, engineers and technicians, some of whom at this conference have referred to "high visibility," cooperative international efforts in environmental protection and energy policy, should not lose sight of the press's unique opportunity to reach the people.

POLITICAL FACTORS IN THE DEVELOPMENT AND IMPLEMENTATION OF TECHNOLOGY-BASED CONFIDENCE-BUILDING MEASURES

by

Gerald M. Steinberg

POLITICS AND CONFIDENCE-BUILDING MEASURES

The second half of the 20th century has been characterized by the continuous development and improvement of weapons of mass destruction, including strategic bombers, missiles, chemical and biological agents, and of course, a variety of nuclear weapons. These weapons pose serious danger to a world that, politically, has not changed much since the days of Hobbes or even Thucydides. In contrast to the massive change in military capabilities brought about by the rapid development of science and technology, international relations is still dominated by relations between sovereign nation states and characterized by distrust, narrow interests, and a continuous war of "all against all."

At the same time that scientific developments created the foundation for the nuclear arms race, however, the scientific and technical community has also sought some antidotes. Technology-based confidence-building measures (TBCBMs), designed to reduce international conflict and to prevent nuclear war, have been proposed by scientists from the US and the USSR. These TBCBMs have taken a number of forms, such as cooperative research and development programs, joint panels and meetings of professional societies, and specially dedicated international forums, such as Pugwash. These have provided a meeting ground for the exchange of views among scientists from many different countries. In addition, a number of more direct forms of TBCBMs, such as satellite-based observation systems and IAEA nuclear safeguards, havenational technical means of verification.

More recently, there have been a number of proposals to apply many of these technologies to the verification of conventional force reduction, arms control, and other confidence-building measures in the context of regional conflicts in the Third World. An International Satellite Monitoring Agency has been proposed to develop space-based technologies such as observation satellites to increase stability and prevent the outbreak of accidental war in regional contexts such as the Middle East. As the rate of proliferation of nuclear, chemical and biological weapons, and advanced missiles and other delivery vehicles accelerates, the application of TBCBMs in regional conflicts is most urgent.

However, despite the development of various technology-based safeguards and the development of joint research projects and other confidence-building measures, the implementation of these measures has been quite limited when compared to the potential range of applications. The formal acceptance of satellite observation for the verification of significant arms-control measures only began in 1972, more than a decade after the technology had been developed. For many years, orbital observation was denounced as being an intrusive violation of national sovereignty, a source of espionage, and the basis for the preparation of a first strike. Similarly, although the basic technology for regional monitoring systems exists, the potential for applying this technology in the contexts of regional conflicts has been ignored or even opposed by many of the countries involved. Links between scientists from countries involved in bitter conflicts in the Third World are generally tenuous, at best, and joint research programs are very rare. Even when such links or programs do exist, as in the case of Israel and Egypt, the "spillover" to the political realm is generally minimal.

To understand the essential problems inherent in the application and use of TBCBMs in various contexts, it is necessary to understand the links between the technology and political processes. It is clearly insufficient to have developed the technology necessary for CBMs, if the political leaders involved are unwilling or unable to implement them. Cooperative research and development projects involving energy, the environment, or space exploration may provide an opportunity for the amelioration of political conflict, but this process is far from automatic. It depends on a variety of political and technical factors, which must be understood in the context of the international system.

DIRECT AND INDIRECT FORMS OF CONFIDENCE-BUILDING MEASURES

While the term "confidence-building measure" is now used quite widely, it is often used to describe different phenomena. By definition, CBMs must go beyond broad international cooperation and dialogue; they must "build confidence" between states in conflict. CBMs can contribute to the relaxation of tensions, to arms control measures, and to the reduction of mutual fears. CBMs are of greatest importance during periods and among states involved in intense conflict. In periods of detente, CBMs can reinforce the political measures but are less salient.

In general, confidence-building measures can be divided into direct and indirect efforts. Direct forms of confidence-building measures generally involve technology or processes that are explicitly linked to the political system and, in themselves contribute to the relaxation of tension, the avoidance of crisis, arms control, and the prevention of war. This category includes technical arms-control related measures, which are often "nonintrusive," such as reconnaissance satellites, IAEA safeguards, and seismic monitoring stations and systems. In addition, there are direct nontechnical measures related to the reduction of international tension, arms limitation, or crisis avoidance, such as the exchange of observers in military exercises involving NATO and Warsaw Pact forces or various communications measures designed to defuse crises and misunderstandings involving the US and USSR. Many of these direct, nontechnical confidence-building measures are defined explicitly in international agreements such as the Helsinki Accords (where the term "confidence-building measures" officially entered the international lexicon) and bilateral agreements between the US and USSR.

Other forms of confidence-building measures, such as cooperative research programs and the exchange of data and of scientists, are based on an indirect approach. Examples of this form include the US-Soviet Apollo-Soyuz space project or the type of energy and environmental research projects discussed in this conference. Although direct confidence-building measures explicitly affect the political interaction between the states involved, the second depends on an indirect influence on the relationship. Direct forms of CBMs, such as satellite monitoring or the exchange of observers, are political acts; they specifically affect the ability of each participant to prepare a surprise attack, and it is precisely for this reason that such measures are directly linked to arms control and tension-reduction processes. In contrast, indirect measures, such as the exchange of scientists, data, and cooperative ventures, must have a spillover effect in order to influence political interaction. Under some conditions, there may indeed be "spill-over" and scientific or technical cooperation may lead or contribute to an easing of political tension. This is not automatic, however, and under some conditions, this form of "confidence building" may have no political impact at all.

The acceptance and impact of each form of confidence building on international relations depends on the political processes and environment. Direct forms of confidence building, such as satellite reconnaissance or IAEA safeguards, depend on the willingness of the states to adopt these measures and on their "interpretation" or application in the political arena. For example, the technology to monitor a Comprehensive

Test Ban with a very high degree of confidence may have existed for some time, but the political factors and environment have been the primary factors in determining the progress towards a CTB. Similarly, technically, the system of nuclear nonproliferation safeguards currently used by the IAEA is far from the technological state-of-the-art, but political factors have prevented the implementation of these technologies.

The role of indirect measures, such as joint research projects, in reducing international conflict, depends on processes of spillover from the technical to the political realms. The scientific and technological community have often placed major emphasis on these international efforts, invoking the "international language of science and technology," and make the claim that science and technology are outside (or in some cases, beyond or above) the limitations of international boundaries and conflicts.

In international relations, the use of technical cooperation to achieve political ends is part of what is known as the functionalist approach. According to this theory, the development of joint working relationships and mutual interests outside of the political realm will eventually lead to a relaxation of tensions and the amelioration of political conflict. For example, this approach was the basis for the development of the EEC in western Europe. At the beginning, cooperative activity was restricted to limited functional efforts, such as the European Coal and Steel Community (which was considered of relatively minor importance), and has steadily built on this cooperative base towards the more complex issues of economic, and ultimately, political unification.

In many cases, however, the spillover or functionalist approach is poorly understood. Few efforts have been made to identify the dynamic processes and conditions necessary for the translation of scientific or technical cooperation into political change and conflict reduction. The evidence shows that such an approach is far from automatic; technical cooperation does not necessarily lead to political cooperation. For example, the 1957 International Geophysical Year (IGY) was, in many ways, a scientific success, but a political failure. As one analyst has noted, the most spectacular result of the IGY was the launch of Sputnik, which "catalyzed the cold war," the missile race, and it was even a factor leading to the Cuban missile crisis. (Bullis in CRS 6/76, p. 53). The Apollo-Soyuz project seemed to be an affirmation of political change and the (temporary) detente of the early 1970s rather than a stimulant of further political change. When the period of detente ended abruptly, so did the variety of cooperative scientific and technical ventures between the US and Soviet scientists.

In order to understand the interaction of political and technological factors in the evolution of both direct and indirect TBCBMs, it is important to analyze the results of efforts in this area to date. To this purpose, this study will focus on a series of case studies in which TBCBMs have been sought. Three cases of direct TCBMs are presented: satellite observation in the US-Soviet context, IAEA safeguards, and the efforts to promote an International Satellite Monitoring Agency (ISMA). In addition, the indirect efforts of the IGY and the Apollo-Soyuz Test Project are examined. By analyzing the political and technological evolution of these forms of TBCBMs and the limitations of political obstacles on the implementation of the technology, some broader guidelines for the development of direct TBCBMs can be suggested.

THE INTERACTION OF POLITICAL AND TECHNICAL ISSUES IN DIRECT FORMS OF TBCBM: SATELLITE OBSERVATION

The deployment of observation satellites represented an early example of a technology-based confidence-building measure. The first US reconnaissance satellite (Discoverer 13) was launched in August 1960. Prior to this period, the US had used high-altitude reconnaissance aircraft, such as the U-2, for

photographic reconnaissance of the Soviet Union. In May 1960, a U-2 had been shot down, and its pilot, Francis Gary Powers, was captured, tried, and convicted. This incident led to an escalation of the conflict between the US and the Soviet Union and a period of crisis in relations regarding Berlin, Cuba, and other points of conflict.

The issue of overhead reconnaissance was clearly of major importance. The US and USSR were then in the process of producing and deploying ICBMs. The Soviets had shocked the US with the launch of Sputnik in October 1957 (demonstrating an ICBM capability), and Khrushchev proclaimed that Moscow was "mass producing" these weapons. According to some estimates, the USSR would have as many as 500 missiles by 1960. This was also a period in which large-scale nuclear tests resumed, and both sides tested multimegaton weapons. During the 1960 US presidential election campaign, the Democratic leaders charged the Republicans with allowing the Soviets to develop a "missile gap." (The evidence from the U-2 flights seemed to indicate that the Soviet production rate was far smaller and that Khruschev was bluffing, but as of April 1960, the evidence was still inconclusive.) In response, the US began to step up its own ICBM production and deployment programs and to take a number of steps to prepare to respond to the threat of a Soviet first strike.

It was in this context that the first reconnaissance satellites were launched. Initially, the Soviets saw the Discoverer (which re-entered the earth's atmosphere with exposed film to and was captured in mid-air or on the surface of the ocean) and its successors as an illegal intrusion on sovereignty and another form of US espionage. There is little doubt that had the technological capability existed at the time, the Soviet Union would have prevented the continued activities of the US reconnaissance satellites. There is considerable evidence that the Soviet military began to develop an antisatellite system primarily to destroy the US "spy satellites." Soviet diplomats in the UN sought to have space reconnaissance declared illegal, arguing that the US was using the satellites as another means of spying, and of identifying the locations of military and important economic installations for the purposes of preparing an attack.

Over a period of a few years, however, the Soviet attitude began to change. In the first place, the public visibility of the US satellite reconnaissance program was kept very low. At the beginning of the program, it received significant publicity in the press (Steinberg, p. 41-43). In 1960, James Killian Jr., who headed the President's Foreign Intelligence Advisory Board, argued that publicity of the reconnaissance satellite launches would increase the probability of a Soviet response. Immediately upon taking office, the Kennedy Administration ordered a blackout on all publicity concerning these launches. While this blackout, which is still largely in effect, is often explained in terms of security considerations, the initial motivation was clearly to limit the degree of Soviet reaction. Civilians in the Administration censored articles and speeches of Air Force officials that dealt with these launches and capabilities. Since, as critics noted, the launches and orbits were easily observed, it is clear that the purpose of secrecy was political) (Steinberg, p. 58).

This policy was part of a broader effort by the US to develop a "climate of legitimacy" for space-based observation. Civilian space flights in the context of NASA's manned Mercury program, as well as unmanned earth-observation satellites, passed over many countries. As this became accepted, and as photos and other data from space became commonplace, space-based observation became more acceptable. Efforts to have these systems declared illegal in the UN or to develop a foundation for the use of antisatellites to disable or destroy reconnaissance satellites decreased in intensity.

At the same time, the Soviet Union found that space-based observation could serve its interests as well, not only for monitoring the US, but primarily with respect to China. During the early and mid-1960s, the PRC was in the process of developing its own nuclear and missile capability, and this was a period of growing tension and military clashes between the USSR and PRC.

Most importantly, after a series of crises in Berlin and the Cuban Missile Crisis in October 1962, Washington and Moscow began to seek means of reducing the risk of accidental war and preemptive strikes. In this context, the use of "observation satellites to promote international security" began to be discussed. US Deputy Assistant Secretary of State Richard Gardner stated that "Space photography can contribute to the reduction of risks of war ... And it is a use of space which may prove important someday in monitoring disarmament agreements" (p. 61).

A State Department official was more explicit:

"Another important potential use of observation in space is the possibility of acquiring information about military preparations and thus help to maintain international peace and security. (One of the great problems in today's world is the uncertainty generated by the secret development, testing and deployment of national armaments and by the lack of information on military preparation within closed societies.) If in fact a nation is not preparing a surprise attack, observation from space could help us to know this and thereby increase confidence in world security which might otherwise be subject to added and unnecessary doubts."

The escalation of the nuclear arms race in the late 1950s and early 1960s, in which the US believed that the Soviets were expanding their ICBM capability significantly, led the US to increase its own missile force. This, in turn, contributed to Khruschev's decision to place missiles in Cuba, which triggered the Cuban missile crisis. Both sides feared that the other was preparing to launch a surprise attack, or at least develop the capability to do so, and both powers accelerated the deployment of missiles in response to such fears.

Following the Cuban missile crisis, the US and Soviet Union resumed efforts to reach agreements on limiting the nuclear arms race. Negotiations on limits to nuclear testing had been stalled for some years over the issue of on-site inspection. The introduction of satellite reconnaissance provided a means for nonintrusive verification that no tests were being conducted in the atmosphere. Tests in space and underwater could also be detected by technical means.

In 1972, over ten years after the technology was first used, the SALT I agreement formally and explicitly established the principle of noninterference with national technical means of verification. Article XII of the 1972 ABM Treaty and Article V of the SALT I agreement, signed in Moscow in May, 1972, state:

1. "For the purpose of providing assurance of compliance with the provisions of this treaty, each Party shall use national technical means of verification at its disposal in a manner consistent with generally recognized principles of international law.
2. Each Party undertakes not to interfere with the national technical means of verification of the other Party operating in accordance with paragraph 1 of this article.
3. Each Party undertakes not to use deliberate concealment measures which impede verification by national technical means of compliance with the provisions of this treaty."

This system allows the US and USSR to monitor adherence to the agreements and provides a basis for mutual assurance that neither side would interfere with verification. In addition to barring physical interference or destruction of satellite observation systems, this also means that facilities and deployments that are covered under the terms of these agreements cannot be concealed in a manner that would interfere with verification. For example, construction of SLBMs must allow for a means by which the number of launchers can be verified. The agreement also created the Standing Consultative Committee (SCC), which meets whenever disputes arise, including over questions regarding possible interference with the ability to

verify adherence to agreements and limitations. Thus, the satellite observation regime evolved into a system not only of passive noninterference but one of active cooperation.

THE IAEA SAFEGUARDS SYSTEM

The IAEA was established in 1957 as an autonomous agency within the framework of the UN. It is charged with promoting the peaceful uses of atomic energy while also preventing the diversion of nuclear facilities and materials to military programs. To this end, the IAEA operates a system of safeguards that are designed to provide "timely detection" of any significant diversion and, thereby, to deter such diversion or to allow the international community to take action in response.

Under the 1967 Nuclear Non-Proliferation Treaty (which went into effect in 1970), signatories that are nonnuclear-weapons states agreed to place all nuclear facilities and materials under safeguards. As critics note, however, the five nuclear-weapons states recognized by the treaty are under no such limitations but are required to conduct all transfers of nuclear materials and facilities through the IAEA and to place these transfers under safeguards.

A number of nuclear-threshold states (or potential nuclear-threshold countries) are not signatories to the NPT and have not accepted safeguards. These include India, Pakistan, South Africa, Argentina, Israel, and, Brazil.

The safeguard system has, in many respects, been a major international accomplishment. Safeguards include surveillance cameras placed to monitor facilities and materials, seals to detect tampering, accounting methods to determine whether diversion has taken place, and inspections. The Agency is responsible for safeguarding over 8 000 kilograms of separated plutonium and 13 200 kilograms of HEU, operates 325 camera systems, and inspects some 600 facilities. This is adequate for most of the states in the system, which, in any case, have no interest in developing nuclear weapons.

However, for those states that are not above suspicion, like Iraq or Libya, and that have sought to acquire nuclear-weapons materials and facilities under the guise of a "peaceful" nuclear program, the system is not adequate.

With respect to these states, the safeguards system is technologically obsolete, understaffed, and far from providing the maximum level of safeguards. (The 1986 Safeguards Implementation Report states that "verification activities were incomplete, which means that the inspection goal could not be evaluated as even partially attained in 1986. In such cases, the level of assurance provided by agency safeguards is substantially below that applicable to verification standards" (Spector, p. 314).

Perhaps more importantly, the safeguards system is enveloped in and subordinate to political processes. In general, the IAEA system is a compromise between the technical requirements of an effective set the use of measures to prevent diversion and the political infringement on national sovereignty and the degree of intrusion that the nonnuclear-weapons states are willing to accept. The safeguard agreements for every country and facility are the result of negotiations between the IAEA and the countries involved. In some cases, countries refuse to meet the requirements of the IAEA or seek to negotiate less stringent safeguards. Spector notes that in 1981, in the case of Pakistan and India, IAEA was unable to confirm that no diversion had taken place because these states did not allow IAEA to install all the necessary monitoring equipment deemed necessary (p. 456). In addition, the safeguards agreements and the data gathered by the safeguard system is secret (this measure was originally justified as a means of protecting proprietary commercial information, although this is no longer considered to be of significant importance). The inspectors' reports

and any indication of diversions are delivered to the IAEA Secretary General and Board of Governors, which then is authorized to determine whether, indeed, a diversion has taken place and then reports its findings to the UN Security Council.

Each of these stages, from the negotiation of the safeguards agreement through the selection of inspectors and other personnel in the safeguards division to the deliberations of the Board of Governors, is essentially political. Although states may not formally choose the inspectors assigned to their facilities, they have the right to veto inspectors from some states, so that India may refuse to admit Pakistani inspectors, and the reverse. This system, however, can be exploited by some countries to insure that only inspectors from certain "sympathetic countries" be assigned and raises very serious doubts about the reliability of the system.

Even if a possible discrepancy is found, there is no assurance that it will be disclosed in "a timely manner." The disclosure of such a finding involves a political decision, which individuals, such as the Secretary General and the representatives of the states that constitute the Board of Governors, may be reluctant to make. Economically or militarily powerful states that are represented on the Board of Governors may seek to cover up findings regarding their own discrepancies or to fabricate claims regarding enemies not represented on the Board.

In summary, the safeguard system has three major weaknesses:

1. The nature of the technology, which, despite claims to the contrary, prevents definitive confirmation that diversion has not taken place;
2. The secrecy in which the safeguard data and the procedures employed for individual states is shrouded; and
3. The opportunities for political manipulation that exist in the system.

Although the political restraints and the issue of secrecy are difficult to change (the NPT and the IAEA safeguards are ultimately voluntary undertakings, and each country is free to renounce either at any time), the technology applicable to safeguards can be updated and improved significantly. Technology is now available that would provide continuous real-time data on reactor power outputs, any form of tampering with nuclear material, and other aspects of the nuclear fuel cycle, but to date, most of the efforts to upgrade the safeguards to the state of the technological art have been resisted, essentially as a result of political factors (USGAO May 1981, pps. 42-48). In some cases, states have something to hide and thus seek to limit the effectiveness of safeguards. In other cases, each improvement on the safeguards technology is considered a further intrusion and an infringement upon national sovereignty. Here, the distinction between the nuclear-weapons states, for whom no intrusive measures are demanded, and the nonnuclear-weapons states is important.

The relationship between political conditions and the technology of safeguards can be illustrated in the case of the Middle East. Although Iraq is a signatory to the NPT and placed its nuclear facilities under IAEA safeguards, the Iraqi government was clearly pursuing a nuclear-weapons program before Israel destroyed its facilities in 1981. (The acquisition of a graphite reactor, which Iraq acquired from France, hot cells, from Italy, and other purchases were obvious evidence of these intentions (see Spector, p. 208). Subsequent testimony provided by former IAEA inspectors (Richter) indicated that the safeguards were not effective in the case of Iraq. In addition, had a diversion been reported to the Board of Governors, action might have been blocked by the Arab representatives on the Board sympathetic to or even supporting the Iraqi effort. Similarly, although Libya signed the NPT, Ghaddifi is still pursuing a nuclear capability. (Spector notes that Libya sought to extract nuclear technology from India by terminating oil sales.)

Given the continued hostility and threat from the Arab states, which, with the exception of Egypt, have been in a state of war with Israel for the past forty years, it is not surprising that Israel has expressed its lack of confidence in the current safeguard system and is unwilling to agree to the NPT requirements. The current system does not provide Israel with "timely warning" of Arab nuclear-weapons development or, as is clearly the case with Iraq and Libya, the assurance that no such development was taking place. Furthermore, Israelis note that the IAEA, like other UN organs, is exploited for anti-Israel propaganda. Should Israel accept safeguards, there is no guarantee that information gained from these safeguards will not be exploited by the Arab states, or that reports of diversion will not be fabricated (like reports of Israeli-South African cooperation, which are published by UN agencies) to isolate Israel politically.

As a result, while Israel and the Arab states accuse each other of escalating the regional nuclear-arms race (now linked to the production and deployment of chemical and biological weapons and missiles), the current IAEA safeguard system does not provide a satisfactory alternative. To generate confidence, the data from a safeguard system would have to be available directly on an equal basis to all the parties "in a timely manner" (continuous real-time monitoring of facilities and materials would provide such a system). Such a local system, based on mutual inspection and safeguards without the intervention of politically constituted third parties such as the UN or IAEA, could be encompassed within the verification system of a regional nuclear-weapons free zone (NWFZ), such as has been proposed by Israel.

THE INTERNATIONAL SATELLITE MONITORING AGENCY

A number of analysts have argued that the technology and space-based satellites that are used to monitor and verify US-Soviet arms-control agreements and other confidence-building measures could also be usefully applied to other regions of the world and the conflicts that occur in those regions. Proposals for the development of a broad international monitoring agency have been discussed since the mid-1960s in the context of Pugwash and in other settings (Jasani and Sakata, p. 129). In the 1978 UN Special Session on Disarmament, the French government proposed the creation of an International Satellite Monitoring Agency for this purpose. According to this proposal, the ISMA would provide satellite data to states for the purpose of monitoring arms control, separation of forces, and other agreements. In 1983, a UN Commission that investigated the proposal in further detail reported that such a system was technically feasible and "could be built up in stages to include image processing, data transmission and satellite facilities." The report also concluded that such a system was not inconsistent with international law. However, the costs were estimated to be greater "than any previous international/technical undertaking" (Krass).

A series of further international meetings were held and reports issued supporting the idea of international monitoring. France has continued to play a major role in this process, as part of its general international political strategy designed to find a global role between two superpowers and also as a means of expanding or even financing its own observation satellite program. (The French government operates the SPOT earth-observation satellite and was developing the SAMRO (satellite militarire de reconnaissance optique) system until the costs of the latter become too great.) As Chairman of the EEC, French President Mitterand called for Europe to "launch its own manned space station allowing it to observe, transmit, and consequently avert all possible threats" (Jasani and Sakata, p. 135). The issue was discussed in Pugwash symposia in France and Sweden, at the 1982 UNISPACE conference, at special conferences in the Netherlands and Japan, as well as in meetings of the Western European Union and the assembly of the Council of Europe. While the ISMA has been discussed widely, it is still far from being implemented. Frequency spectrum, periodicity of the orbit, resolution, data distribution, etc., are all important factors in any such

space-based system, and the technical details necessary for the operation of developing such a system in a regional context are complex.

More importantly, there are a number of major political obstacles to the implementation of this system on a world-wide or even regional basis. Neither the US nor the Soviet governments have shown much enthusiasm for the ISMA proposal. In the UN, the USSR voted against the establishment of such an agency, and the US abstained (Jasani and Sakata, p. 129). The US has also rejected proposals to make US technology or data from US military reconnaissance satellites available for this purpose (Krass, and Jasani and Sakata, p. 117). Although the US and USSR have recognized mutual interests in using satellite observation in the context of their relationship, they also have an interest in preventing the proliferation of this capability. For example, the US used its satellite reconnaissance information in planning its response to Libya's involvement in a number of terrorist attacks and to monitor activities in the Persian Gulf while the US was involved in escorting oil tankers during the Iran-Iraq war. Had a similar capability been available to Libya or Iran, the US forces in the region would have been more vulnerable to attack. The Soviets, similarly, had their own reconnaissance-satellite information for use in the conflict with the PRC and in Afghanistan. The establishment of an ISMA with independent capabilities would end the superpower advantage in this area.

In addition, very few Third World countries have expressed much interest in the IMSA concept; on the contrary, many have expressed a degree of distrust or opposition (Jasani and Sakata, p 130). In contrast to the case of the US and USSR, which operate their own satellite reconnaissance systems, the IMSA system and its satellites would not be under the control of the countries involved but rather, as specified, under the control of an international agency. In many cases, particularly involving regional powers, there is little trust or confidence that vital national interests would be protected by an international agency (this is comparable to the perception of IAEA safeguards, as discussed above). Thus, the proposals for a ISMA in the context of the UN or other international agency have made little if any progress to date.

INDIRECT TBCBM: THE IGY AND THE APOLLO-SOYUZ PROJECT

Scientists and the members of the technical community are often described and describe themselves as an international a-political society (Wood). According to this view, science transcends the boundaries imposed by nationalism and politics, and although nations may quarrel, scientists, "speaking an international language," can continue their work on behalf of mankind and even thereby help elevate politics to the level of cooperation and joint progress. In some cases, such as the Franco-Prussian War of 1870, and even, to a limited degree, World War I, the scientists from the opposing states continued their cooperation, despite the conflict. (Of course, other scientists helped develop weapons and military technology, but that is a different issue.) Furthermore, according to this apolitical, transcendent approach to international relations, joint R&D efforts and international scientific cooperation can actually change the political system and lead to a reduction of tensions, arms control, and even world peace.

Empirically, the results of this approach are mixed. Some international efforts, particularly in the area of food production (the "Green Revolution") and health measures (the campaigns against smallpox and polio), are very successful. Others, particularly those that touch upon politically "sensitive" areas, such as space exploration and atomic energy, have proven to be less successful.

One of the largest-scale efforts to translate the "international language of science" into concrete terms took place during the International Geophysical Year (actually, July 1957 to December 1958). Tens of

thousands of scientists from 67 nations took part in a variety of coordinated and cooperative efforts designed to enhance understanding of the Earth. Scientifically, the achievements of the IGY were very impressive. The political spillover of this cooperation, however, was limited, at best. International cooperation in the context of the IGY did nothing to temper the Cold War or the nuclear arms race. Indeed, as noted above, the launch of Sputnik was perceived both by the Soviet Union and the US as a major political and military success for the Soviet Union, heightening tensions and contributing to the American missile buildup that followed.

The Apollo-Soyuz Test Project (ASTP) and the "handshake in space" that it produced also provides a prominent example of technical cooperation that failed to contribute to political change, the easing of tensions, or conflict amelioration. The agreement that led to the ASTP and a number of other joint scientific and technological cooperative measures was signed in Moscow in 1972, during the summit that also produced the SALT I and ABM accords. As Walter McDougall notes, "The ASTP was obviously a creature, not a cause, of detente, and it gave Soviet technicians the chance to traipse through US space facilities and study the hardware and flight operations firsthand." Not long after the ASTP, and at the height of the exchange of US and Soviet scientists and other joint projects, detente failed, and the Cold War returned. Only with a change in the political environment and the rise of Gorbachev and "glasnost" were cooperative scientific and technological programs started again.

As in the context of the US-Soviet relationship, the application of TBCBMs to regional conflict depends fundamentally on political variables. Although a number of joint or cooperative technical and scientific projects involving Israel and its Arab neighbors, including the joint development of water projects, have been proposed, political limitations and, in particular, the absolute refusal of the Arab states to have any links with Israel, have blocked the implementation of these projects for over 40 years. In the decade since the peace accords were signed between Egypt and Israel, a number of joint and cooperative scientific and technical efforts have been initiated, and although there are some agricultural and health projects under way, they have not had any discernable impact on political links on the Egyptian government and the "cold peace" that characterizes Egypt's policy.

Thus, the evidence seems to indicate that although such cooperative measures can enhance political cooperation, it is very difficult to generate a spillover effect onto the political environment. Politics, not technology, is still the independent variable.

LESSONS AND IMPLICATIONS

Technology-based confidence-building measures are explicitly designed to alter the political climate. By generating or building "confidence," they are expected to contribute to the development of communications, and even trust, between conflicting states. Although such cooperative ventures, whether between the US and USSR, India and Pakistan, or Israel and the Arab states, might contribute to the overall development of scientific knowledge or the improvement of the human condition, unless they further political progress, arms limitations, the prevention of war, and contribute to conflict resolution, they must be judged as unsuccessful as confidence-building measures.

In the past, from the evidence available, it would appear that although all forms of TBCBMs are difficult to implement, direct measures, such as technology used to verify compliance with arms limitation agreements, have been the most successful. The satellite observation regime, IAEA safeguards system, and similar measures have indeed contributed to confidence building, arms-limitation, and the amelioration of

conflict. However, the success of these measures depends on the response of the political environment. It is important to recognize that technology-based confidence building measures are usually seen as intrusive, and indeed they usually are. The ability to observe military installations, bases, weapons and troop movements from space is an important factor in any country's national-security considerations, and those states that are involved in intense conflicts are reluctant to allow this information to be disseminated. In most cases, the military and national-security establishments see secrecy as a major military asset and would view TBCBMs that would reduce the level of secrecy with suspicion.

Application of proposed TBCBMs to regional conflicts (such as the development of an International Satellite Monitoring Agency) would have to overcome fears that the data and information that is acquired and disseminated was not used for offensive or aggressive purposes, which would, of course, counter the purpose of the TBCBM concept. For example, a means would have to be devised to insure that satellite data would not enable states to target their enemies, to prepare a first strike, or to exploit the information in other ways. Without these safeguards, the establishment of which are by no means trivial, the TBCBs, far from serving the cause of peace and conflict prevention, could easily be turned into sources of instability and war.

As a result, as illustrated in the cases discussed above, the formal development and negotiation of a set of TBCBMs depends on the cooperation of the countries involved and, in particular, on the realization among the leaders of these states of a common interest that can be served by the implementation of TBCBMs. In the case of satellite-observation involving the US and USSR, this occurred in the wake of the 1962 Cuban missile crisis and the common fear of accidental war caused by instability and the mutual fear of first strike. Similarly, to the degree that IAEA safeguards have been accepted, this is a result of the common fear of the consequences of nuclear proliferation.

At the same time, the refusal of some states to place their nuclear facilities under IAEA safeguards is based, in part, on the absence of a perception that this would increase their national security. As in the case of the US and USSR during the height of the Cold War, political leaders in many countries do not see any possibility of cooperative action, such as is embodied in a system of TBCBMs, that might reduce dangers for them as well as their enemies. In this sense, political detente and rapprochement is in many ways a precondition for the explicit acceptance and cooperation with and application of TBCBMs.

Thus, it is very important to create these preconditions by making the leaders of regional powers aware of the existence of common dangers inherent in conditions of instability, mutual fear of first strike, etc., and to also understand the potential common interests in avoiding these situations. Such dangers are particularly important in the case of proto-nuclear weapons states (with bombs in the basement) and states with developing chemical and biological weapons and missile delivery systems. Such forces generally have not been tested extensively, if at all, and command and control-loop systems are also unreliable (absence of PAL systems). Once leaders are aware of these dangers and deficiencies, they should be more open to the consideration of TBCBMs, even at the cost of some intrusion on national sovereignty.

In the absence of such a realization of common interests, political limitations suggest that rather than seeking a formal international agreement to operate a TBCBM system in the framework of a UN-affiliated organization, informal, more gradual and unilateral or bilateral approaches are more likely to be successful. This is also apparent from the histories of the development of the existing forms of TBCBMs and the contrast between the US-Soviet reconnaissance satellite regime and the IAEA safeguards system.

The strengths, as well as the weaknesses of this approach can also be examined in the case of the US efforts to impose full-scope safeguards on all of the recipients of US nuclear exports (to limit the transfer of plutonium from civil reactor programs) and in the case of the French SPOT observation satellite.

The prospects for success in indirect forms of TBCBMs, such as joint R&D projects, are even more limited. The evidence indicates that the scientific and technological community is not automatically apolitical, and any spillover must be carefully prepared and guided through the political minefields. To be successful, TBCBMs must work with knowledge of the political constraints and within the given political environment, rather than ignoring these factors. For example, in the Middle East, proposals for measures requiring direct negotiations between Israel and Syria regarding missile limits must recognize that the Syrian government has refused to hold direct negotiations with Israel on any subject for over 40 years.

It is important, however, to see the intersection between these two forms of TBCBMs. In both cases, individual scientists play an important role. The importance of science and technology in the political system of any country has given members of the technological community access to the political leadership. Indeed, members of this community are increasingly becoming part of the political leadership. Scientists who can both understand the critical technical issues in areas such as weapons development, energy, and the environment and can understand the language of politics can bridge these two worlds.

International scientific organizations and groups such as Pugwash can provide a link between the the world of politics and science. These professional and ostensibly apolitical platforms can provide a unofficial and indirect forum for the discussion of common interests and, on this basis, for the development of TBCBMs. If the scientific community can create an awareness of the mutual interests in dealing with common problems, such as the dangers posed by the proliferation of advanced weapons of mass destruction and by the threat to the global environment posed by the individual actions of separate states, they will have created the foundation for political action. The accomplishment of this first step would be a major contribution.

Furthermore, during a period of US-Soviet detente and progress towards arms control, it is also important to turn the efforts of TBCBMs towards regional conflicts in the Third World. Indeed, there have been a number of proposals to apply many of these technologies to the verification of force reduction, arms control, and other confidence-building measures in these contexts. An International Satellite Monitoring Agency has been proposed to develop space-based technologies, such as observation satellites to increase stability and prevent the outbreak of accidental war in regional contexts such as the Middle East. As the rate of proliferation of nuclear, chemical and biological weapons, and advanced missiles and other delivery vehicles accelerates, the application of TBCBMs in regional conflicts is most urgent.

The failure to implement regional TBCBMs, such as the ISMA, to date is also a reflection of the critical role of political factors. Here, as in the case of the early clashes between the US and USSR over satellite reconnaissance, the fears of espionage and the use of satellite data for the preparation of a surprise attack is dominant. These conflicts are still largely seen in terms of "zero-sum games," and the threat to all sides posed by the proliferation of missiles and chemical, biological, and nuclear weapons is poorly perceived.

In this environment, discussion of technology-based confidence-building measures could play an important role in creating an understanding of the common interests and mutual threats and, thereby, in building the foundation on which TBCBMs could be adopted in regional contexts.

NOTES:

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ENERGY SECURITY IN A COMPETITIVE WORLD

by

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The world is shrinking and becoming increasingly interconnected. Events in one part of the world quickly impact other parts of the world. Rising standards of living in developed countries, along with rapid communications and growing, mobile populations, go hand in hand with greater worldwide interconnectedness but at the same time are leading to a greater rate of resource depletion. Adequate and economical energy resources are one of the crucial factors in maintaining and increasing standards of living around the world, yet nonrenewable energy resources are being depleted.

The international marketplace is also becoming more tightly interconnected and competitive. Increasing trade competition among nations may contribute to greater economic efficiency and, on the whole, to improved living standards in successful countries, but competition also contributes to barriers against cooperation. International trade competition may be leading to a tendency for competing nations to become more parochial in technology research and development.

The impact of growing populations and rising living standards on the world's environment is also increasing and becoming more pervasive. Solid waste disposal is an increasingly aggravating problem, and hazardous and toxic wastes are even more difficult to deal with. Acid rain, global climate change, ozone-layer depletion, stream and harbor pollution, and the resulting pollution of the oceans are all evidence of a highly interconnected world.

It is easy to argue that solutions must be political, economic, and social. In large part this must be the case; but as technologists, we want to do all we can to give political, economic, and social forces the best opportunity to succeed. Technology will be part of the solution and not just part of the problem of securing adequate energy supplies with acceptable environmental impact.

ENERGY SECURITY

Energy security is a much debated, but poorly defined, topic. A main thrust of energy policy in the U.S. since the Arab oil embargo of 1973 has been to improve energy security with the dominant objective to set policies and develop technologies to help reduce reliance on imported oil. Oil dominates energy markets; no satisfactory substitutes have been developed; and it has become the one irreplaceable fuel. It is the only energy medium of this kind: it is relatively ubiquitous in source and use; it can be easily stored in nearly end-use form; it is transportable; and it can replace all other energy sources (but others cannot easily replace it, particularly in transportation). Current global proven oil reserves will last about five decades at today's production rates. The problem is, however, that the global distribution of reserves is very uneven. About 70% of current proven reserves are in the Middle East. Exploration to discover new non-OPEC reserves and development of new technologies to exploit residual oil in known fields become extremely important in this context.

Fortunately, in the late 1980s the world has a large excess oil production capacity (about 10 million bbl/day[1] or about 20% of current worldwide production). Oil moves freely in the world market, and prices are relatively low and stable. Thus, energy security is not as immediate a problem as it appeared to be in

the seventies. An unfortunate result of this is that energy technology research and development programs are not nearly as popular nor as well funded. Further, at current rates of oil-demand increase, the current excess production capacity will be gone by the year 2000 (albeit new capacity can be added relatively easily in the Persian Gulf region). It is, therefore, still highly important to consider energy security seriously and to address energy technology R&D in this context.

An important consideration is the dependence of real and perceived energy insecurities on timing. For the very short term, i.e., months, the greatest energy security concern is that of sudden disruption of even small amounts (e.g., a few percent) of oil supplies to those countries most dependent on imported oils (including the U.S., Western Europe, and Japan). Such a disruption can cause prices to soar, which in turn can cause a major economic disruption. The insurance to protect against such short-term disruptions can be composed of many parts, e.g., stored strategic reserves, conservation, ability to replace oil with other supplies, an open, highly interconnected international market, and multilateral allocation of supplies (as in the emergency allocation process for the U.S., Western Europe, and Japan member nations of the International Energy Agency). These measures, along with the worldwide excess production capability, have taken the edge off the short-term supply disruption problem compared to the situation in 1973-74. A sudden, unexpected small drop in production from any of the major producers would likely set off a round of hoarding and price shocks, but the market would probably adjust relatively quickly.

The more critical problem over the mid-term (the next few decades) is that of the changing mix of suppliers as production declines and reserves begin to be depleted in areas outside the Persian Gulf. The U.S. has less than a 10-year supply of proven oil reserves at current production rates. Production is falling in the lower 48 states and cannot be sustained in Alaska much longer without additional fields. Most of the other major producers outside the Persian Gulf region have reserves sufficient for only a very few decades. Granted, this does not take into account undiscovered resources and enhanced recovery techniques, but it also does not take into account increasing worldwide demand. In any event, there is the likelihood that in a few decades worldwide oil production will shift far more to the Persian Gulf than now.

Of course, gas, coal, and other sources, including nuclear energy, could increase their contributions substantially and delay this shift. Currently, gas, hydropower, coal, nuclear, and other non-oil sources supply about 56% of the total energy consumed in the developed countries.[1] Non-oil fossil reserves are substantial. Gas reserves can provide an energy equivalent nearly that of oil reserves, and coal can provide many times that of oil. As is true for oil, the reserves are unevenly distributed around the world, with the Persian Gulf region and Soviet Union having major shares (30% and 40%, respectively) of gas reserves, and the U.S. and U.S.S.R. having major shares (almost 30% each) of coal reserves. One key to decreasing oil demand is to provide economic conversion of gas and coal to liquid transportation fuels.

Nuclear energy can also play an important role in lessening oil demand, as it already has, by increasing its use in electricity generation. However, it is difficult to believe that present-generation nuclear plants will be further deployed rapidly enough to substantially increase their present fraction of total electricity generating capacity. Indeed, in the U.S. the nuclear-generation share of total capacity could drop significantly as demand increases (presently at nearly 4% annual rate of increase), no new nuclear plants are deployed (none have been ordered since 1978 and are not likely to be for some time), and older plants reach the end of their design life and are shut down. Replacing older plants will require substantial new generating capacity to be added in the 2000-2020 time frame in the U.S.

Beyond the next few decades, the long-term problem is that of replacing fossil sources with one or, hopefully, more of the "inexhaustibles:" solar, the fission breeder reactor, fusion, and geothermal (when hot dry rock or magma geothermal are included). The challenge of today's energy-technology development

programs for each of these is to show that each can be competitive with the marginal energy production costs from the current dominant source, i.e., oil at $15-22/bbl. This is a worthy challenge. Certainly if, for example, solar photovoltaics breakthroughs could lead to electricity production costs in the few cents/kwh range, then our energy concerns would be considerably ameliorated. However, since Middle East oil-production costs are below 3$/bbl rather than the $15-22/bbl present prices, it is plausible that OPEC would simply drop prices to maintain or even increase its total energy market share and, in the process, drive higher-cost oil production out of the market.

As we have seen in the past two years, there are strong internal pressures within OPEC to maximize total profits, which indicates OPEC will maintain prices as high as possible relative to competition from other sources. For this reason, it is very important in the near to mid-term for other energy technologies to strive to compete with oil prices in the $15-22/bbl range. "Staying close" even without greater market penetration is very important from both an energy security and economics viewpoint. Even if oil alternatives cannot beat a $15/bbl price, they will provide a ceiling if they are readily available. From the energy security viewpoint, we must always be ready to replace oil with other only slightly more costly (hopefully) sources. This, of course, does not address trade balances or movement of wealth problems, which could also in themselves make greater investments in energy-technology development worthwhile. Further, for the long term, we must make sure that inexhaustible sources will be available when necessary at costs that are economic and will have acceptable environmental and social impacts.

ENVIRONMENTAL EFFECTS

Environmental impacts could shortly become more of a driver of energy-use patterns than production costs or supply security. We do not yet know whether the impacts of extensive fossil fuel use, (e.g., air pollution, acid rain, and, possibly, global climate change) will lead to an early curtailment of their use or, perhaps more likely, to financial disincentives imposed on their use. We are beginning to feel more directly the economic impacts of nuclear-fission power-use curtailment due to perceived safety and environmental impacts. Whether justified or not on a technical basis, pressures to reduce public risk from reactor accidents and radioactive waste transportation and storage, combined with the costs of new plant construction, have led to the current hiatus on further deployment of commercial nuclear plants in the U.S. for the foreseeable future.

TECHNOLOGY CONTRIBUTIONS

Certainly, improved and new technology must begin to make more substantial contributions to energy and environmental needs as we go into the 21st century. Also, energy conservation can be substantially improved, which helps in both energy and environmental arenas. For example, the U.S. DOE Energy Security report[2] of 1987 provides a range of conservation scenarios that would yield energy savings equal to 5-12 million bbl/day oil equivalent by the year 2000.

Reducing oil imports by increasing energy efficiency requires a broad set of programs. Research on automobile engines and materials has provided a unique opportunity for the DOE weapons laboratories (Lawrence Livermore National Laboratory, Los Alamos National Laboratory, and Sandia National Laboratories) to use their substantial experimental and computational modeling capabilities. As a result of this

program, funded by the DOE's Energy and Conversion Technologies (ECUT) Office, the nation's automotive industry is investigating innovative engine designs that improve fuel economy and reduce emissions. Funding by the ECUT Office has also resulted in new, high-temperature materials that can be used in energy-conservation applications. This latter initiative has resulted in 22 licenses to industry. A "Materials by Design" program, also sponsored by this office, is developing computation techniques that will accelerate the development of new materials.

Renewable energy must also contribute more substantially in the future. To quote from the Energy Security report: "the United States and the world will, in time, come to rely largely on energy sources that are essentially inexhaustible, possibly including advanced nuclear fission reactors, fusion, and many diverse sources that are commonly lumped under the term 'renewable energy.' ... The combination of solar, wind, geothermal, hydropower, and biomass energy represents an extremely large resource base that, over the long term, could become a major new source of energy supply. Perhaps the greatest advantage of these renewables is simply that they are based on technology, rather than on insecure resources. The resources that underlie them (including innovative ideas) are indigenous. They are not subject to politically induced disruptions. Their costs are likely to drop, rather than rise. By its very definition, renewable energy can significantly reduce energy security problems, but only whenever and wherever it is available at a reasonable cost, in sufficient quantities, and in the desired applications. The very presence of additional, substitutable energy options in the marketplace will tend to moderate the size and frequency of swings in conventional fuel prices... Renewable-energy technologies have excellent export potential in the developing countries."

Because it is indigenous, renewable energy is secure and provides a range of flexibility and options unobtainable with other sources. For example, there are active solar markets in states with widely differing climates—including Arizona, Colorado, Florida, and New York. Passive solar heating techniques, a large part of which were developed at Los Alamos, are being incorporated in buildings and homes throughout the United States. Geothermal energy, now available only in California and a few neighboring states, can be developed in every region of the U.S. by exploiting the Hot Dry Rock technology being developed by Los Alamos.

Solar photovoltaic technology is making substantial progress; this has already resulted in significant cost reductions. Continuing technical advances in materials and concentrator technology can lead to improvements in durability and efficiency—and eventually perhaps to costs that can compete with conventional electricity generation technologies.

Over the long term, there can be no doubt that technology-based applications of renewable energy can promote secure and adequate energy supplies at stable, predictable costs. Renewable energy is based on abundant, diverse, nondepletable resources available in every region of the U.S. Most renewable energy technologies can be assembled in relatively small building blocks or modules, which permit additions to energy supply in smaller units than is common for conventional technologies. This is a distinct advantage when energy demand projections are uncertain and when growing financial risks are associated with construction of large supply units such as more conventional generating plants.

Enhanced oil-recovery technology can make substantial contributions and is particularly valuable to the U.S. in terms of the capability for replacing imported oil. In January 1988, DOE Assistant Secretary for Fossil Energy, Allen Wampler, announced "the core of a new initiative" in enhanced oil recovery at an address to the American Society of Mechanical Engineers: "Our target must be the estimated 300 billion barrels of oil in this nation that is either immobile or is mobile but currently unrecoverable." Since oil was discovered in 1859, somewhat more than 130 billion barrels have been produced, so this is a huge target. This new initiative was announced, according to *Inside Energy*, after a nationwide survey of the

private and state sectors, conducted by the DOE, revealed a consensus for an expanded federal role in oil-recovery R&D "as long as it is done in partnership, not in competition, with the oil industry." The initiative is to address: 1) reservoir characterization; 2) drilling technology, well completion, workover and equipment retrofit; 3) environmental aspects; and 4) novel concepts for enhanced recovery. One outcome of this initiative is the new Oil Recovery Technology Partnership program just established between Los Alamos and Sandia National Laboratories to work on enhanced oil-recovery technologies in partnership with U.S. oil companies.

Similarly, in response to several national concerns, the U.S. DOE has established the Clean Coal Technology program. These concerns include the need to address acid rain and related environmental issues, reduced employment in coal producing states, the decline of "smokestack" industries, technology to augment the stagnant nuclear power industry, and the necessity to develop a more competitive U.S. technology base opening up export markets for both the coal resource and coal technology.

At a recent conference at Los Alamos National Laboratory on "Support for the U.S. Coal Industry by the National Laboratories," emphasis was placed on the need for advanced research for coal. Research needs were identified in many areas, including:

- coal combustion modeling,
- conversion of coal-derived syngas to methanol,
- development of coal slurry engines,
- in-situ techniques to produce residual methane, and
- fuels for nonutility applications.

Safe, economic nuclear power is also needed to meet future electricity generating capacity needs. The growth rate in electricity demand in the United States is now about 4% per year rather than the projections of 2% per year made only a few years ago. Replacing existing, but aging, coal-fired and nuclear generating plants in the next few decades while also keeping up with the growth in demand will require building hundreds of new plants. Nuclear power must be an available option to meet these needs because it provides the only proven alternative to continuing to burn fossil fuels for large-scale generation of electricity. Electricity has increasingly become the end-use energy of choice. Of long-range potential is the development of fuel cells and advanced batteries as power supplies for vehicles—the major consumers of oil and the heaviest contributors to air pollution. Regenerating vehicle energy storage from the electrical grid during off-peak hours can more efficiently and fully use available capacity.

A rapid deployment of new nuclear plants in the U.S. during the next decade is not possible; in fact, new commercial plants are not likely to be ordered in the near future. Many problems remain to be solved before new orders are placed. Most importantly, public confidence in nuclear safety must be regained. This can be accomplished by developing and demonstrating improved designs and assuring a safe and environmentally acceptable high-level radioactive waste repository. Among the advanced designs that could be deployed in the future are the Modular High-Temperature Gas-Cooled Reactor and the Integral Fast Reactor, which also offers the promise of an essentially inexhaustible source when used in a uranium-235 breeding fuel cycle.

Finally, proving the technical and economic feasibility of magnetic-confinement fusion energy could provide the needed assurance of a long-term and essentially inexhaustible energy source that would be environmentally attractive compared to fission energy. Practical fusion energy is many decades away and is an enormous undertaking best approached through substantial international cooperation, as is already occurring more than in any other energy technology area.

As is true for long-term energy technology development, environmental assessment also calls for extensive international cooperation. Technology can add much to this process. Particularly in global climate change assessment, large-scale modeling using supercomputers is essential, even if still needing improvement. International cooperation to extend data bases is strongly needed.

MODELS FOR INTERNATIONAL COOPERATION

International cooperation is readily presumed to be a good thing, but at the same time the reality is that nations are competing fiercely—from superpower military arenas to sales of high-technology manufactured goods and basic commodities, including oil, and achieving greater cooperation requires considerable care. The most basic level of needed cooperation is to define a set of rules that keeps the game on a level playing field, such as rules establishing free market access. A second level involves establishing cooperative allocation of constrained resources, such as in the IEA emergency oil-allocation process. Finally, cooperation among nations is most worthwhile if it goes further than these two levels and improves on what would otherwise be a zero-sum competitive game. This is the most important area for exploring new modes of international cooperation, including those in which U.S.-Soviet scientific cooperation could lead the way.

There are a number of close-to-home examples that can serve as models of bilateral, multilateral, and international cooperation. One of the most interesting areas of U.S.-Soviet cooperation in recent years is that of verifying that underground nuclear tests stay below the 150-kiloton yield threshold established by the Limited Test Ban Treaty. The two Joint Verification Experiments performed in 1988, one at the U.S. Nuclear Test Site in Nevada and the other at the Soviet test area at Semipalatinsk, both with side-by-side U.S. and Soviet participation, showed a remarkable degree of cooperation, considering the national security sensitivities of nuclear testing. The somewhat parallel opening of each of the two countries to on-site inspection teams and short-notice inspections for verification of the Intermediate Nuclear Forces Treaty is equally remarkable.

Verification is important in cooperative ventures, particularly when the stakes are very high as in superpower nuclear deterrence. In the similarly sensitive nuclear safeguards area of detecting the diversion of nuclear materials from civilian to military purposes, countries who are signatories to the Nuclear Nonproliferation Treaty agree to allow inspectors from the International Atomic Energy Agency to perform unannounced inspections of sometimes commercially sensitive nuclear facilities. In the verification and safeguards situations, countries give up a small degree of their sovereignty voluntarily to assure that all involved abide by the rules. Verification is an important concept that can provide assurance (an extra degree of trust) that an agreement will be followed.

Science and technology cooperation often falls into two categories. The first is simply the open scientific interchange of ideas and technical results that occurs through open publications and conferences. In this case, participants tacitly accept the notion that all gain through open scientific exchange. The second category includes formal scientific agreements in which people, funds, equipment, and/or data are exchanged on a fair-trade basis. Many of these have occurred in the energy technology area. At Los Alamos, we have been involved in U.S.-Soviet magnetic fusion energy information exchanges for three decades now. We have also been involved in specific international exchange programs in hot-dry-rock geothermal energy (U.S., Japan, and the Federal Republic of Germany), in reactor safety (U.S., Japan and the FRG, also the U.S., France, U.K., Japan, and the FRG), in tritium systems R&D for magnetic fusion energy (U.S. and Japan), in reversed-field-pinch magnetic fusion energy (U.S., European Community, and Japan), and in nuclear safeguards bilateral agreements between the U.S. and Japan. Beyond these official agreements,

there have been many other informal but extensive scientific collaborations in such areas as solar energy and fuel cells.

A somewhat different kind of cooperation in the energy area is that of technology assistance. Los Alamos, through a program funded by the Agency for International Development in the U.S. Department of State, provides energy and mineral resource assessment and development assistance to six countries in Central America. One of the fundamental ideas in this program is for these countries to develop more of their own infrastructure for planning and using their indigenous energy resources, such as hydrothermal energy, to decrease their dependence on imported oil.

From past and current examples of cooperation we can learn much that is relevant to greater international cooperation in energy and environmental technology areas and to energy security even in the context of increasing international trade competition. Countries can cooperate in precommercial research and still remain highly competitive in the commercial arena.

We need stronger international cooperative efforts in global climate change and ozone-layer depletion assessment. International agreements limiting discharge of chlorofluorocarbons are moving forward. Similar agreements limiting fossil fuel burning would be much more difficult to implement but could ultimately be necessary if global climate change proves to be a real effect and there are no alternatives. Increased international cooperation in providing technical assistance to lesser-developed countries in developing renewable energy sources is worth considering as one way to lessen the impact on these countries if fossil fuel burning eventually must be restricted. Technical assistance in reforestation may also be reasonable. In energy technology areas, continued international cooperative programs are essential, particularly in precommercial areas. There can also be strong advantages to pursuing large-scale demonstrations through multilateral programs, such as is being done in magnetic fusion energy with the International Tokomak Engineering Reactor (ITER) project.

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REAL-TIME GLOBAL MUTUAL AID FOR ATMOSPHERIC RELEASES OF RADIOACTIVITY IS POSSIBLE TODAY

by

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ABSTRACT

Over the past 15 years, the Lawrence Livermore National Laboratory's Atmospheric Release Advisory Capability (ARAC) has developed and evolved a computer-based, real-time, radiological-dose-assessment service for the United States Departments of Energy and Defense. This service is built on the integrated components of real-time computer-acquired meteorological data, extensive computer databases, numerical atmospheric-dispersion models, graphical displays, and operational-assessment-staff expertise. The focus of ARAC is the off-site problem for which regional meteorology and topography are dominant influences on transport and dispersion. Through application to numerous radiological accidents/releases on scales from small accidental ventings to the Chernobyl reactor disaster, ARAC has developed methods to provide emergency dose assessments from the local to the hemispheric scale.

As the power of computers has evolved inversely with respect to cost and size, ARAC has expanded its service and reduced the response time from hours to minutes for an accident within the United States. Concurrently, the quality of the assessments has improved as more advanced models have been developed and incorporated into the ARAC system. Over the past six years, the number of directly connected facilities has increased from 6 to 73. All major US Federal agencies now have access to ARAC via the Department of Energy as specified in the US Federal Radiological Emergency Response Plan. This assures a level of consistency as well as experience. ARAC maintains its real-time skills by participation in approximately 150 exercises per year; ARAC also continuously validates its modeling systems by application to all available tracer experiments and data sets.

While the most recent major application of ARAC to a real accident event was the Chernobyl disaster, ARAC spent a considerable effort and was well prepared for the potential COSMOS 1900 reactor burnup. Preparation for events such as these provides the impulse for further improvement in data acquisition, databases, mapping, and models.

ARAC could provide significant assistance in support of a radiological accident anywhere in the world if requested/authorized by the US Department of Energy. Modern telephone communications in combination with telefacsimile technology provides the possibility for contact between ARAC and appropriate national/international agencies or officials. With the recent addition of global topography and access to worldwide meteorological data, ARAC can rapidly provide emergency assessment calculations based upon a tested and verified system of models and databases.

INTRODUCTION

The Atmospheric Release Advisory Capability (ARAC)[1,2,3] is a United States Government Department of Energy (DOE)-sponsored emergency-response service designed, developed, and established at Lawrence Livermore National Laboratory (LLNL) to provide real-time predictions of the radiation dose levels and the extent of surface contamination resulting from a broad range of possible occurrences or accidents that could involve the release of airborne radioactive material. During its 15-year lifetime, ARAC has responded to more than 300 real-time situations and exercises. Some of the most notable responses include the Three Mile Island (TMI) accident[4] in Pennsylvania, USA, the Titan II missile accident[5] in Arkansas, USA, the reentry of the USSR's COSMOS-954 into the atmosphere over Canada, the accidental release of uranium hexafluoride from the Sequoyah Fuels Facility accident[6] in Oklahoma, USA, and, most recently, the Chernobyl reactor accident[7,8] in the Soviet Union. On several occasions, ARAC has served on extended alerts, e.g., for COSMOS 1402 (1983) and COSMOS 1900 (1988), or served in an advisory and confirmatory role for the US federal government, such as for the purge of the Krypton 85 from the TMI containment in the summer of 1980.

ARAC currently supports the emergency preparedness plans and activities at Department of Defense (DOD) and DOE sites within the US, and also responds to any accidents that the US has interest in, e.g., Chernobyl. Our ARAC center serves as the focal point for data acquisition, data analysis, and assessments during a response, using a computer-based communication network to acquire real-time weather data from the accident site (supported facilities) and the surrounding region, as well as pertinent accident information. Its three-dimensional models for atmospheric dispersion process all this information and produce the short-term (2–6 hour) projections used in accident assessment.

Our work has received international recognition and acceptance. In 1980, we transferred our ARAC models to the computer system of the Italian Nuclear and Alternate Energy Agency (ENEA), and we continue to cooperate with ENEA in the areas of model evaluation and system development.[9] In 1982, ENEA transferred our ARAC models to the computer system of the Japanese Atomic Energy Research Institute (JAERI), and we have developed a close working relationship with JAERI. In 1983 we transferred our ARAC models to the Swedish National Defense Institute (NDI), and we have pursued model evaluation studies with NDI. We have provided consulting services with regard to emergency-response atmospheric models and computerized emergency-response methods to the International Atomic Energy Agency and have presented a 2-1/2-day course in computerized emergency response for developing countries. In addition, we have provided our key models and various services to Spain, Korea, Brazil, Israel, West Germany, and India.

BACKGROUND

The Atmospheric Release Advisory Capability is a real-time emergency response and preparedness service developed at Lawrence Livermore National Laboratory. ARAC provides projections of dose level, concentration, and surface contamination resulting from a broad range of possible occurrences (e.g., accidents, spills, extortion threats involving nuclear material, reentry of nuclear-powered satellites, atmospheric nuclear tests) that could involve the release of airborne radioactive material. During the past 15 years, ARAC has responded to or participated in approximately 300 situations—most exercises, but also all major nuclear accidents/events.

The original concept, prototype development, and initial operations (1974–1982) were funded by the DOE. A major expansion, entailing redesign and increased automation, was accomplished (1983–1986) with major funding by the DOD. In 1987 a Memorandum of Understanding (MOU) was negotiated between the DOE and DOD for an even division of operational funds to support a 40 hour/week "immediate" and off-hours "as available" response service for the 50 then-supported/planned sites. Subsequent sites and services have been added on a proratable-cost-share basis so as not to jeopardize the basic service level of the MOU-covered sites.

The present ARAC is prepared to:

- Rapidly assess environmental impacts, using three-dimensional atmospheric-dispersion models that include the effects of complex meteorological conditions and terrain;
- Support the emergency-preparedness plans at over 70 DOE and DOD facilities accessible through our computer system; and
- provide timely impact assessments for accidents that occur at any location in the world.

Support for DOE is not only provided to specific sites/facilities, but also to its specialized emergency response and assessment organizations, i.e., the Accident Response Group (ARG) and the Federal Radiological Monitoring and Assessment Center (FRMAC). ARAC participates in most major exercises of these groups. DOD also receives ARAC support for its many major exercises, training courses, and accident manual/procedures development. Exercise preparation and development for DOE, DOD, and the Nuclear Regulatory Commission (NRC) is another frequently utilized aspect of the ARAC service.

DESCRIPTION OF ARAC

ARAC is both a service and a system. The ARAC emergency response and assessment service is the integral result of (1) the applied expertise of its 27-person operations and support staff, (2) extensive databases, (3) the application of sophisticated models, (4) an extreme emphasis on preparedness, and (5) a high degree of computer automation. The present staff composition is approximately half operations (assessment meteorologists, system operators, equipment support, etc.) and half computer programmers.

The ARAC emergency response and assessment system is a combined software/hardware structure based on a "central" system and distributed user-terminal support components. Such a design focuses the computational load (and power) at a central location (ARAC) and, through a communications system/network, supports a user terminal or mini-computer with site-specific information, local data, and central system-prepared advanced model calculations. The ARAC central system consists of clustered Digital Equipment Corporation (DEC) VAX-8550 and 780 computers (VMS), associated disk storage (approximately 12 Gbyte), and peripheral (graphic, text, and printer) devices. The communication system consists of two Micro-VAX II computers with 33 modems linked with DECNET to the main VAX cluster. Additionally, the remote user site system has been developed for a DEC Professional Computer 350/380 (PC-350/380) with the Professional Operating System (POS) and Telephone Management System (TMS) incorporating a proprietary communications protocol. At sites with a meteorological tower, dedicated microprocessors (HANDAR 540) manage the data collection and transmission of that data to the site computer.

The above described integrated system of hardware and software is called the ARAC Emergency Response Operating System (AEROS). Presently, as a result of the automation developed in AEROS, ARAC can:

- Produce initial emergency assessments within 25 minutes of notification during normal working hours for sites connected to our computer system (future improvements of the system will reduce this response time to about 15 minutes);
- produce high-quality graphical displays of the assessments of radioactivity in the form of isopleths (contour lines) on a map (see Fig. 1);
- provide a simple user-friendly interface for data entry and system operation; and
- manage multiple emergencies at a wide range of possible locations.

In developing AEROS, we used modern structured-analysis and design programming techniques to make the system simpler to maintain and alter as evolution has required. AEROS incorporates many features that make it highly reliable, most notably, extensive variable-range checking and PASCAL language data-type checking. Its meteorological data-acquisition and processing functions, as well as its model input-parameters selection process, are highly automated to reduce delays and human error. These latter features enable the system to reliably keep pace with changing developments in an emergency situation.

Figure 2 schematically outlines the hardware, which is essentially a network of computers and communication equipment. The AEROS system presently includes approximately 70 nuclear facilities. At each of these facilities, there is a meteorological tower and a DEC PC 350 or 380 with a hard disk, color monitor, telephone-management system, and dot-matrix printer. At some facilities the instruments on the meteorological tower transfer data directly into the on-site computer through a modem, whereas at the others an operator transfers the information manually. Information from the facility computer, together with detailed weather data for the surrounding area obtained from the US Air Force Global Weather Central, (Omaha, Nebraska) feeds directly into the ARAC central computer system at Livermore, California.

The flow of information and data for a response is depicted in Fig. 3. Operations staff at the ARAC central facility can initiate a response using an on-line questionnaire for entry of accident information received via telephone or telefax, collect meteorological data, simulate releases using complex dispersion models that account for the effects of local terrain, prepare graphical displays of all projections overlaying the local geography, and distribute these projections to on-site authorities.

Site computer users can initiate a response at the central facility by entering accident information into an on-line questionnaire. To report an accident, an operator at an ARAC-supported facility selects an "alert" or "emergency" condition on the local computer system menu. This action initiates a fully automated dialup connection task, transparent to the user. Immediately thereafter, a problem questionnaire is displayed prompting the user for pertinent accident information such as time, location, description, and any supplemental meteorological data (primarily wind speeds and directions, although temperature, barometric pressure, and humidity can also be important). This information is automatically transmitted to the ARAC central facility. Receipt of an "off-normal" condition from a site immediately triggers a paging system that alerts the ARAC staff and sets in motion the data-acquisition system that gathers all available regional and site weather data for input into the model calculations.

MODELS

At the core of the ARAC system is a suite of diagnostic models, which are fully integrated into our emergency response environment, i.e., computers, communications, databases, etc. The primary model suite is actually a six-code stream:

- TOPOG (topography/grid generation)[10]
- MEDIC (meteorological data interpolation)[10]
- MATHEW (mass adjustment/balance)[11]
- ADPIC (atmospheric dispersion, particle-in-cell)[12]
- DOSE (dose factors)[10]
- PLOT CONTOUR (graphic contour plots)[10]

Upon initiation of a problem or emergency response, once the region of concern and problem scale have been determined, the terrain-grid-generation program (TOPOG) produces a $51 \times 51 \times 15$ grid cell or block form rendition of the terrain features to serve as the lower boundary of the modeling domain. Immediately thereafter, the previously requested meteorological data, automatically decoded and processed, is input to a meteorological spatial-data-interpolation program (MEDIC), which prepares a $1/R^2$, three-station-influenced, initial reference-level gridded wind field. This low-level grid is then matched/extrapolated vertically to fit a representative tall tower or upper-air wind profile, thus completely initializing the three-dimensional grid volume. Boundary-layer and mixing-layer depths, wind-profile power-law exponents, stability, etc., are either entered by ARAC's assessment meteorologist or automatically selected by a hierarchy of algorithms. These initialized grid values are then passed to a mass-consistent wind field model (MATHEW), which minimally adjusts the flow fields by removal of mass divergence through horizontal and vertical wind-component balance to satisfy the law of mass continuity. The resulting mass-balanced, terrain-influenced wind fields serve as the transport (flow) fields for the atmospheric-dispersion, particle-in-cell model (ADPIC); lateral and vertical dispersion/diffusion are treated by a K-theory, gradient diffusion scheme. The dispersing (toxic) hazard material (up to 9 different substances) is represented by a set of marker particles (maximum = 20 000) released either instantly (puff) or continuously (plume), with simulated properties of gases or particulates (with size distribution and gravitationally driven settling), time-variable source rate, half-life decay, deposition velocities, and washout/rainout interaction. The ADPIC model can be set to calculate instantaneous concentration, time-integrated concentration (dose), and time-accumulated deposition arrays (grids) for selected levels (surface and aloft), which can then be further processed with a dose-conversion-factors (DOSE) program and, individually or in combination, isoplethed and displayed with selectable contours (e.g., PAGs, EAGLs, DERLs) over geographical maps, and with appropriate legends, etc., by means of a graphics-processing (PLOT CONTOUR) program. This model stream has been validated numerous times against field-program tracer studies and real-world accidents.

Prior to Chernobyl, ARAC had a minimally tested hemispheric code, PATRIC, which was derived from ADPIC. Though forced to use the PATRIC model for the real-time Chernobyl response, ARAC has since expanded and adapted a version of the full six-code suite to deal with large-area (continental to hemispheric-scale) calculations through incorporation of gridded analysis and forecast data from the US Air Force Global Weather Central (AFGWC). ARAC also has a sophisticated puff-diffusion model, 2BPUFF, and a nuclear-explosion fallout model, KDFOC, as well as continuous- (plume) and instantaneous- (puff) point-source Gaussian models integrated into its emergency response system for application to relevant problems. For satellite reentry-type problems, ARAC has adapted an orbit prediction code (PREDICT) to

calculate and display the orbital ground track of the vehicle, based upon orbital parameters available from NORAD (see Fig. 4).

DATABASES

One of the important inputs to the model calculation comes from topography databases. Terrain information is needed by the models so that material is dispersed in a manner consistent with the wind and temperature fields influenced by the underlying terrain.[13] In two to five minutes, ARAC operations staff create the essential files and call up images of the mountains, valleys, seashores, and plains for any part of the United States (from a 0.5-km database) and the world (from a 8-km database) on their computer screens. The topography databases used to construct these images are produced by the Defense Mapping Agency for the United States and by the National Ocean and Atmospheric Administration (NOAA) for the world.

Monthly, ARAC receives an updated list of all reporting meteorological stations (location, elevation, etc.) in the world and their reporting statistics. This information is loaded into a Master Station Library database from which ARAC software can automatically extract key information about all stations within a given radius of an accident/location, initiate automatic data requests, and locate the stations in three-dimensional space for model initialization.

Extensive geographic mapping databases exist[14] or are under development for a full spectrum of scales, i.e., detailed site maps to hemispheric/global maps. Sources of this data include the US Geological Survey's (USGS) 1:2 000 000-scale Digital Line Graph (DLG) data, the Central Intelligence Agency's World Data Base II, and detailed site maps processed through an ARAC digitization process. ARAC intends to add USGS's newest product, the 1:100 000 DLG mapping data, as soon as possible.

In the past year, ARAC completed the implementation of an on-line Dose Factors database consisting of internal dose conversion factors published in the ICRP-30 report. For external dose conversion factors, we have incorporated those compiled by Kocher.[15,16] At some future date, ARAC anticipates the development of a substantial demographics database.

PREPAREDNESS

The underlying cornerstone of effective emergency response is preparedness, both in terms of the development and exercise of procedures and in terms of the acquisition and cataloging/databasing of all possible static data. ARAC has developed and maintains "default" essential data files for all supported sites. Also, detailed site notebooks have been prepared for each site. A "potential accident site" library has been constructed for all US potential accident sites, i.e., nuclear power plants, fuel-cycle facilities, etc. ARAC is attempting to expand this library to include all sites worldwide. This information, in conjunction with the above mentioned terrain, mapping, meteorological station location, and dose factor databases, postures ARAC in a high state of readiness.

The extensive effort invested in the automation of all these essential databases and data acquisition processes, coupled with conversion of all possible manual tasks to automated functions, has resulted in reduction of ARAC's initial response time for an accident from $\sim$ 60 minutes to $\leq$ 25 minutes. With

planned software changes this year, we anticipate a further reduction to a ~ 15-minute response without further hardware upgrades (see Fig. 5).

Complementing this extensive data preparation and staging effort is an active exercise program, which finds ARAC constantly testing its entire system and assuring its readiness to perform (see Fig. 6). Tracer studies and other opportunistic events are used to evaluate and validate the entire system.

EVOLUTION

Technological changes, such as new generations of computers, communications systems, graphic (color) terminals, etc., have provided a continuous opportunity for system evolution in terms of performance speed, reliability, and appearance over the last decade. Likewise, the application of new software development tools and methodologies have improved the reliability and management of this aspect of ARAC.

However, beyond these evolutions, each major accident/event over the life of ARAC has pointed out shortcomings of our emergency response service.[17] Many of these were somewhat compensated for by extensive real-time manpower efforts, albeit, usually at a significant cost in delay of our response. A "nested-grid" version of ADPIC was developed and implemented to provide good spatial resolution for calculations near an accident location. As a result of these events, ARAC has developed an automated meteorological-data-request and management system that can acquire raw data immediately, and decoded or processed data within 20 minutes or less, for anywhere in the world. A continental US topographic database has been developed and implemented such that 0.5-km-scale data can be retrieved and processed within two minutes, for inclusion in ARAC's three-dimensional modeling system. Also, model product labels, legends, display areas, etc., have been changed to alleviate interpretation difficulties. Numerious in-house procedures have been developed, and many have been automated, to reduce the manual tasks, which could slow a response. A "nested-grid" version of ADPIC was developed and implemented to provide good spatial resolution for calculations near an accident location.

In the model area, Chernobyl proved that the need for long-range transport and dispersion calculations existed, but ARAC was not immediately prepared to respond. After rapidly exceeding the 200-km range of our then existing regional-response capabilities, we defaulted operationally to simple hand and automated trajectory-puff calculations, while the systems development and support staff commenced four major expansion efforts. First, large three-hourly decoded data sets for all of Europe and the western Soviet Union were requested from Air Force Global Weather Central, catalogued, and prepared for model input. Second, the fundamental ARAC emergency-response models, MEDIC, MATHEW, ADPIC, and PLOT CONTOUR, were expanded to cover a 2000-km-square region and all the encompassed data stations (see Fig. 7). Third, after radioactivity was measured over Japan, an inactive hemispheric R & D model (PATRIC), derived from ADPIC, was rapidly brought to operational status and tested for applicability to the Chernobyl problem. And lastly, the procedures (requests, conversions, transforms, etc.) to receive and database the hemispheric gridded-data fields from AFGWC were developed and implemented such that hemispheric-scale calculations were available ten days after the accident started (see Fig. 8).

Operationally, today ARAC has its models adapted such that, if required, we could expand up to near-continental scale within a few hours or less. Data quantities, however, would be a problem because a high volume of reports would significantly slow the modeling initialization. At the next scale—hemispheric—we now have an operational version of the ADPIC model and routinely (twice per day) receive gridded wind data from AFGWC for the northern hemisphere north of 20 degrees latitude. Calculations on this scale

could commence in less than two hours, if required. A test of our model, mapping, and AFGWC data demonstrated that we have a capability in the southern hemisphere south of 20 degrees latitude. Since we do not routinely receive the data for this region of the world, any response calculations in this hemisphere would require several hours to acquire the data sets. The tropics region from 20 degrees north to 20 degrees south is not presently covered by any ARAC gridded modeling/data system.

GLOBAL ADAPTATION

Considering the large number of nuclear power plants (~ 500) and research reactors (~ 250) throughout the world and considering the grave response of the general public to the three nuclear-reactor accidents with offsite consequences to date, Windscale, Three Mile Island and Chernobyl, it seems prudent to apply the best available technical assessment tools/systems to nuclear reactor accident emergency-response. Certainly a major issue for political leaders/governments as well as the nuclear industry is the provision of safe nuclear power for industrial development and support. This requires public support and acceptance, something greatly questioned since these accidents have occurred.

Proven emergency response systems/services such as ARAC can serve several key roles for national/international organizations confronting a nuclear reactor accident. First, is the provision of a rapid, early assessment of the immediate and near-term hazards in a consistent, uniform presentation based upon international standards. Second, local emergency response resources can be freed to acquire vital local-area measurements and concentrate on the collection, analysis, verification, and distribution of reliable data. Third, the full regional impacts can be derived from the combination of wide-area meteorological data, proven models, good accident information and validated measurement data without tying up vital on-scene resources needed for accident management and public protection. An additional or fourth benefit is the training opportunity to provide public officials and facility managers with realistic, graphic visualizations of the consequences of plausible accidents so that they are better prepared for the potential time and space scales of a real accident.

Modern telephone and telefacsimile communications make this type assistance available nearly worldwide in real-time. In order to actualize such a worldwide capability, an international organization such as the IAEA, UNDRO, WMO, WHO, IRC, etc., should request the US to make ARAC an international resource. This could also provide some elevated level of confidence and assurance for the leadership of Less Developed Countries (LDCs) who recognize their very limited technological resource base and could project their complete overload in an accident situation.

To make such a service viable at a worthwhile level, a modest effort would need to be expended on data collection, i.e. preparedness, to curtail response time. Also, training-learning exercises should be conducted with the assistance of the appropriate international agencies to assure that the necessary communication links can be established and to develop local site and regional government familiarity and confidence in the entire process. Once adequate training has taken place, the local news media should be advised and trained in understanding the products so that they can communicate this capability to the general public. This last step is the most important in developing and maintaining public confidence, particularly in the presence of a nuclear accident. Proper and confident use of a validated emergency response system will permit local, regional, and national officials to most effectively use their limited resources, communicate with the general public (through and with the media), and engender the vital confidence that public officials have adequate knowledge to make correct (and necessary) decisions in the event of an accident.

At the simplest level of global preparedness, telephone numbers, telefacsimile numbers, contact names, and training information should be gathered into an organized database and periodically tested. Perhaps either international agencies or technical/industry/scientific organizations could provide the leadership for such an effort. Eventually this could lead to routine checks of all communications links and possible regular local exercises.

With the emerging computer and communications technologies, ARAC plans to develop a new-generation emergency-response workstation with 3-D modelling capabilities, industry-standard color graphics and low-cost dialup communications. If such workstations were installed at major reactor sites or emergency management centers, then a real-time global mutual aid system could evolve in place with the potential for support to come from several specialty centers, including specialists concerned with food and agriculture pathways, water systems, animal management, remediation, etc.

CONCLUSION AND SUMMARY

Fifteen years of evolution and experience with a wide spectrum of radiological accidents, two generations of computer technology, extensive databases, models, automation and real-time meteorological data have led to the worldwide-capable ARAC system that exists today. Requests for access to its capabilities by an international organization such as the IAEA, etc., could make this proven emergency-response technology available to the global community. There are no technical barriers, only decisions and nominal support are needed to make this a reality.

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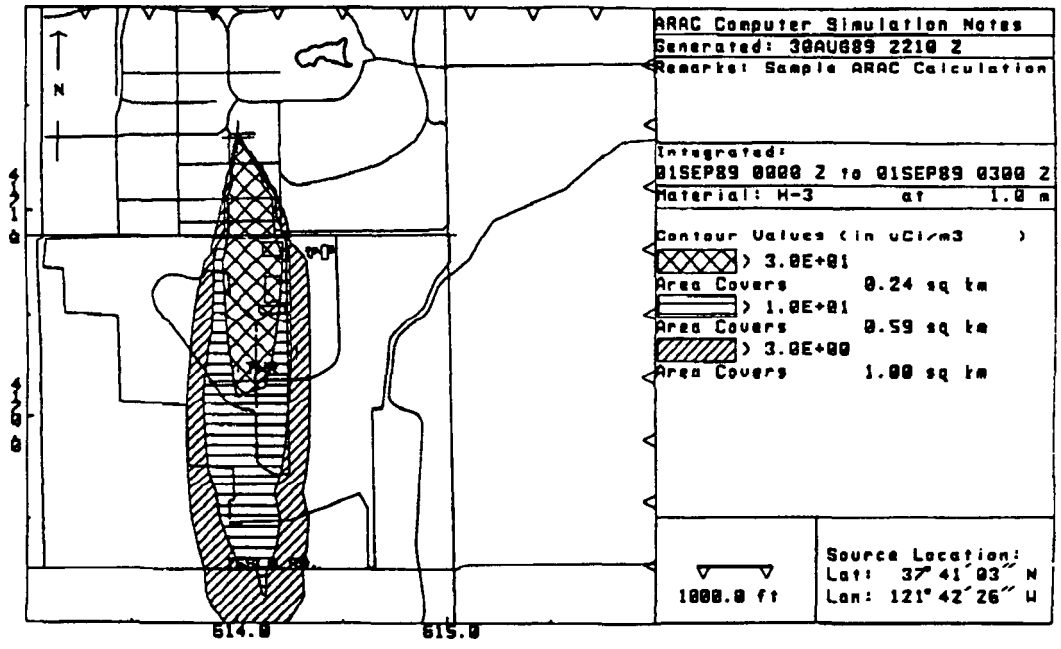


Figure 1. Illustration of a typical ARAC dose-assessment plot (for a hypothetical release at Lawrence Livermore National Laboratory). Contour/area legends, calculation interval, event start time, species, units, etc., are all contained in the information legend. The depiction is always presented on a map background if the map is available.

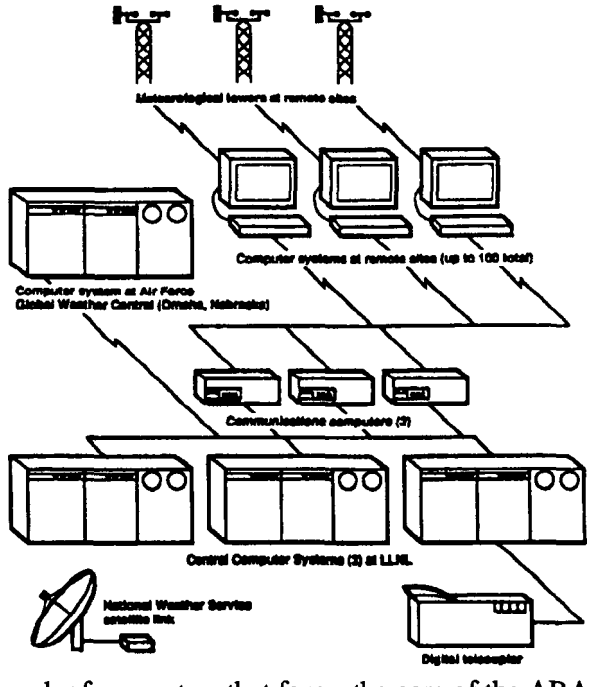


Figure 2. The AEROS network of computers that forms the core of the ARAC system. Each nuclear facility in the system has a desk-top computer for entering initial accident reports and a meteorological tower to provide up-to-the-minute weather data. High-speed data links transmit this information to our computer center for use in atmospheric models.

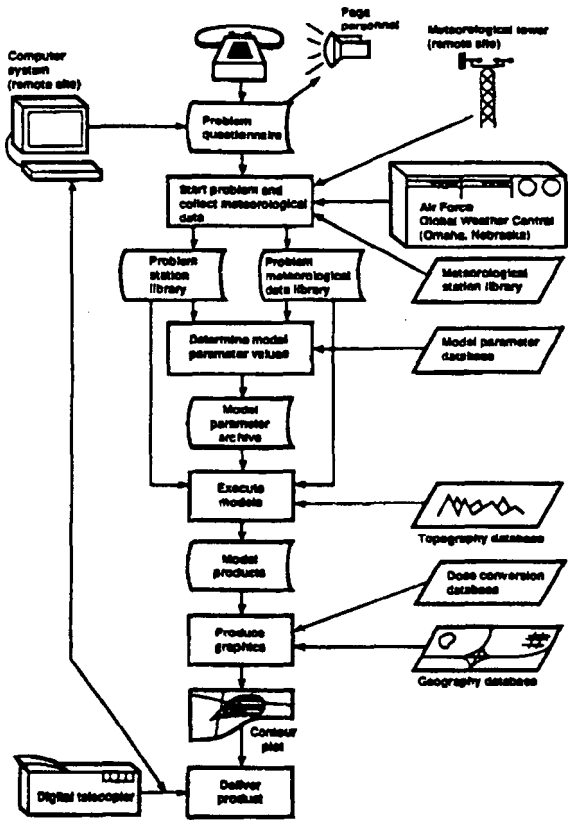


Figure 3. An outline of how the ARAC system functions. When an operator reporting an accident fills out a questionnaire on a computer located at one of the remote nuclear facilities, a paging system sounds at LLNL, alerting ARAC personnel and starting the collection of weather data from the nuclear facility's weather tower and from the Air Force Global Weather Central in Omaha, Nebraska. This information, combined with site-specific and problem-specific data from other libraries, is used to determine parameter values for use in the model. These values, together with information from our topography database, enable us to execute the models, produce graphics such as isodose plots, and distribute the results to crisis managers at ARAC and back at the site of the problem.

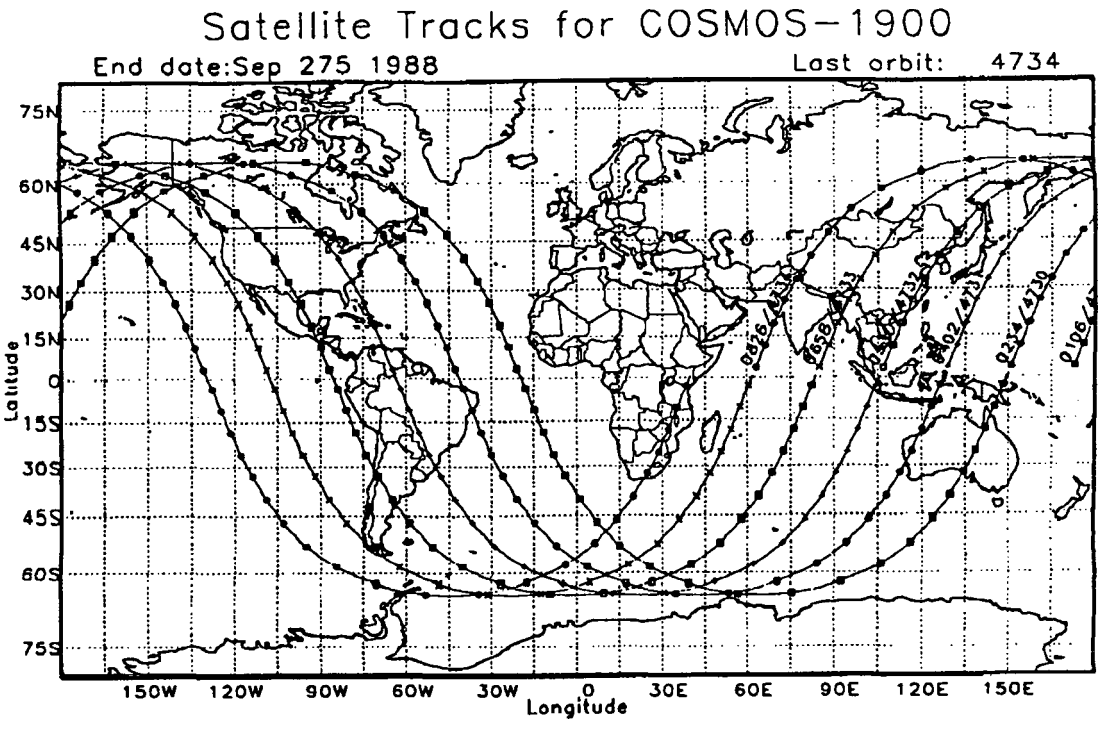


Figure 4. An example of five typical orbital paths of COSMOS 1900, illustrating the everchanging areas of concern until confirmation of reentry into the atmosphere.

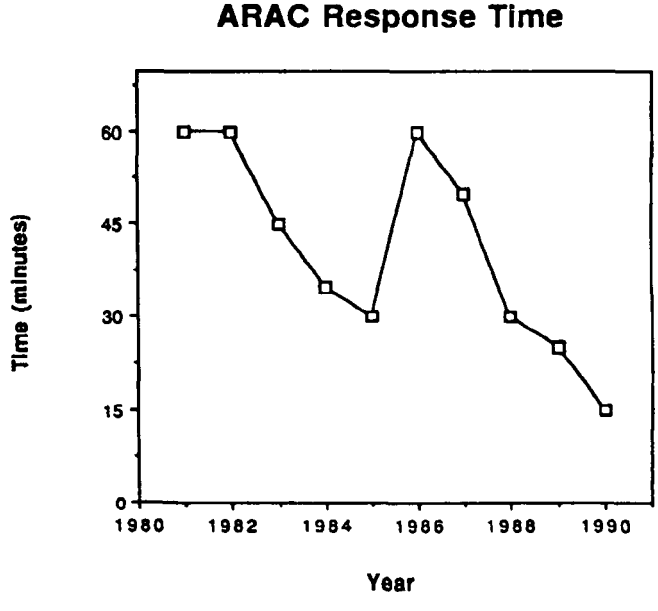


Figure 5. This plot shows how automation of the data acquisition process, databases, and manual tasks has steadily improved ARAC's initial response time. Note that ARAC moved from a CDC 7600 to a DEC VAX 782 in 1986 and to a VAX 8550 in 1988.

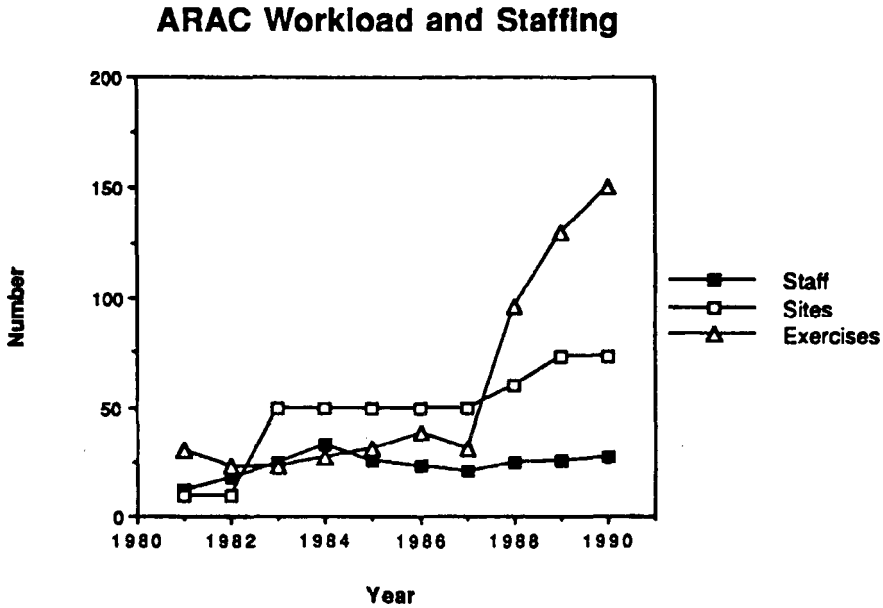


Figure 6. The benefits of automation to productivity are evident in this plot, which shows the chronology of the number of ARAC staff, the number of supported sites, and the number of training/preparedness exercises. It would not be possible to provide the ARAC service to the large number of supported sites and conduct so many exercises without the extensive automation and integration of capabilities as discussed in this report.

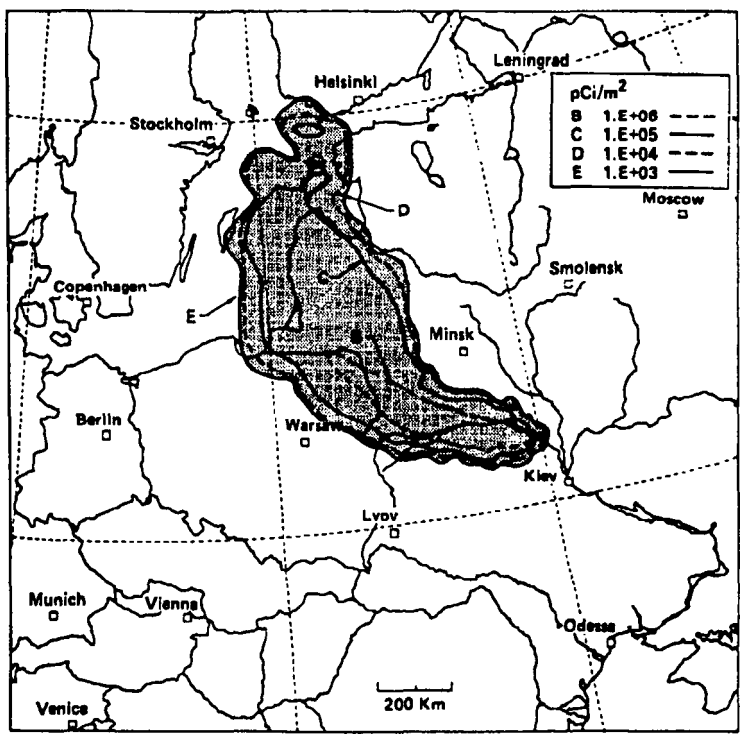


Figure 7. ARAC-calculated Cesium-137 dry-deposition isopleths after 48 hours of simulation based upon an assumed source term for the Chernobyl accident. This plot shows the size of the area, and, by inference, the regional meteorological data, required to generate ARAC's initial assessments.

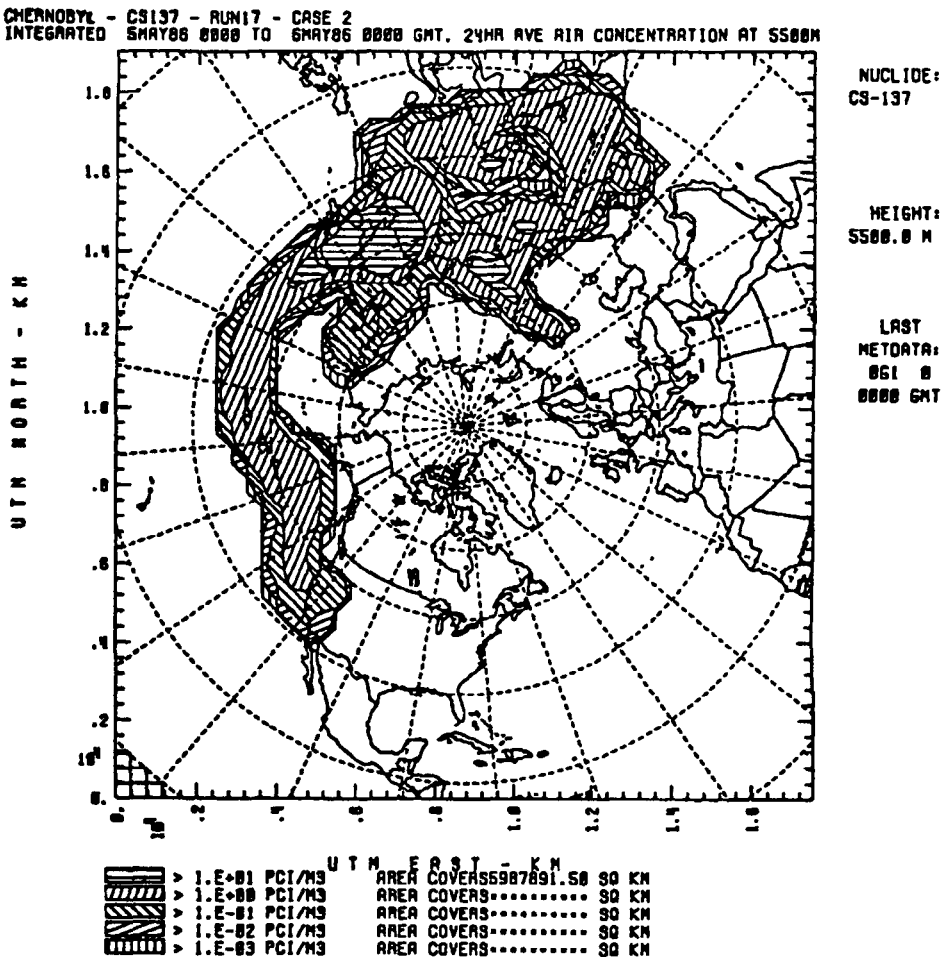


Figure 8. This is an example of a calculation for the Chernobyl accident of the 24-hour average concentration of Cesium-137 in pico-Curies m^{-2} for 5 May 1986 at 5500 m above sea level, produced by ARAC's operational hemispheric transport and dispersion model.

NATIONAL ENERGY PLANNING AND CONFIDENCE BUILDING BETWEEN NATIONS

by

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The main thesis of this paper is that the effects of energy production, distribution and consumption within national boundaries have serious repercussions in neighboring regions and, in some cases, in areas far removed from the source of energy use. This results in increased strains and tensions not only between nations but also within whole regions. By taking into consideration the regional and global ramifications of national energy policies, governments could use energy planning as a means of building confidence between states. This, in turn, could create the political framework for improving and strengthening security arrangements, especially between adversarial nations or alliances.

INTRODUCTION

The past decade has witnessed a growing awareness of the regional and global effects of energy-related activities. Some well-known examples are the production of electricity from coal- and oil-fired plants in the United States and the resulting acid precipitation in Canada, which has created tensions between two otherwise close allies. Plants in England and continental Europe have generated similar environmental problems in Scandinavia and have contributed to strains between nations in the region.

Less well-known cases of adverse cross-border effects resulting from energy-related activities can be found between the United States and Mexico and among the nations that share the Baltic Sea. These two cases will be examined as examples of how coordination of energy planning or adjustments of national energy policies to take into consideration regional concerns could enhance security by building confidence between states of the region. In the first case, we will look at the relationship between the United States and Mexico because it provides an example of an asymmetrical interaction between a wealthy, developed and militarily powerful nation and a poorer, developing and militarily weak state who both share a common 2 000-mile, largely undefended, border.

The second case will consider the Baltic Sea as a vital, regional resource shared by states with different political systems, alliance obligations and levels of economic development.

Despite their differences, they all depend heavily on the Baltic Sea and have a stake in maintaining its viability and ecological integrity.

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UNITED STATES AND MEXICO

Relations between the United States and Mexico have always been, even under the best of circumstances, either strained or openly hostile. Mexicans have never forgotten that almost half their national territory was lost to the United States in the war of 1846 and have traditionally been suspicious of American intentions regarding their country. The United States has historically looked upon Mexico as an alien culture, prone to violent upheavals that could directly affect the United States, and, in recent times, sees it as a source of drugs and illegal immigration.

These negative stereotypes mask, of course, a very complex and increasingly interdependent relationship between the two countries, an interdependence that has a bearing on the security of both states. Although Mexico poses no direct military threat to the United States, the political and economic conditions in Mexico do affect US security. Major disruptions and instabilities in Mexico, a country with over 80 million people and a projected population of 100 million by the year 2000, would surely be felt in the United States, particularly in the four border states.

In fact, it could be said that the United States and Mexico form a "security community," in the sense noted by Karl Deutsch and applied by K. J. Holsti to the relations between the United States and Canada. Deutsch and Holsti point out that a security community exists between two nations when policy makers, as well as the general publics of both countries, neither contemplate the possibility of mutual warfare nor allocate resources for building military capabilities directed at the other.

Such a situation clearly exists between the United States and Canada and also between the United States and Mexico. The communality of interests between Canada and the United States is more obvious than between Mexico and the US because of the strong cultural, political, and economic ties as well as many shared values between the United States and Canada.

Although the history of relations between the United States and Mexico, as well as present circumstances, are significantly different from those between Canada and the United States, there is a broad range of common interests and concerns that also unite Mexico and the United States into a form of interdependence and shared security. Many of these overlapping areas come into focus in the borderlands between the two countries.

Stability in Mexico and good bilateral relations eliminates the need for the United States to secure its long southern border by military means. This, in turn, frees up considerable resources, which the United States uses to meet its many other commitments around the world. The cost to the United States to militarily secure the US-Mexican border would likely be prohibitive.

The basis of a security community between the United States and Mexico, however, goes beyond the military aspects of security and involves the economic and political realms as well. Mexico's important role in World War II as a supplier of raw materials continued during the post-war period. The Cold War reinforced the concept of strategic reserves of various raw materials for national defense and security, and Mexico naturally entered the picture as a reliable source of some of these materials. Generally good relations with Mexico and the ability to transport materials on land across the border assured that supplies from Mexico would be relatively secure. Most recently, the oil crisis of the 1970s and the continued unrest in the Middle East has caused many US observers to view Mexican oil as a strategic material necessary both for defense and for the economic well-being of the United States. Again, the ability to transfer petroleum across a secure border region enhances the attractiveness of Mexico as a supplier of this resource.

PETROLEUM

Indeed, the import of Mexican oil is important in terms of the security relationship of the two countries. Imports of oil from Mexico began increasing significantly in the later 1970s, reaching a peak of 826 000 barrels per day in 1983. At that time, Mexico was the largest exporter of oil to the United States and accounted for 16 percent of all US oil imports. The increase of imports in 1983 enabled the United States to increase its strategic stockpile of oil and provided Mexico with needed cash at a critical time.

Although Mexican oil exports to the United States have declined from a high of 826,000 barrels per day in 1983 to 747 000 barrels per day in 1988, they still accounted for 10 percent of total US oil imports, which itself made up 43 percent of total US oil consumption. Mexico ranks fourth behind Saudi Arabia, Canada and Venezuela as principal exporters of oil to the United States. Total oil exports from Arab OPEC countries accounted for 25 percent of US oil imports in 1988, whereas imports from Canada, Venezuela and Mexico supplied 34 percent of US oil imports. Although the US is not critically dependent upon imported oil from Mexico, a severe disruption would have a major impact on US oil supplies. Likewise, a halt to US purchases of Mexican oil would have a serious impact on the Mexican economy. The United States is a natural market for Mexican oil, considering the geographical proximity and that Mexico has proven to be a reliable and stable source.

The policies related to the purchase, consumption and production of oil is clearly one domain in which decisions made in one country effect the security of the other. By keeping this in mind, national policies could be adjusted to meet the concerns of the other country, thereby building trust and confidence that, over time, will provide a framework for improving relations in other aspects of the bilateral relationship.

For example, because Mexico is important to US security, the United States might agree to purchase Mexican oil at a price somewhat above the prevailing international rate. The price difference would be regarded as an investment to safeguard national security interests by assisting Mexico with its economic difficulties, thereby enhancing stability in the region. This price differential could be relatively small and would not represent an undue burden on the United States but would be appreciated in Mexico and could serve as a confidence-building measure that could have positive effects in other aspects of the bilateral relationship.

Last year the United States purchased 270 million barrels of oil from Mexico. If the US paid 50 cents a barrel above market rates, the additional cost would be $135 million. This is only 0.045 percent of last years US defense budget of $300 billion and represents the cost of three F-15 Eagle air force fighter planes.

Another possibility would be for the United States to subsidize Mexican purchases of US-manufactured oil and gas drilling equipment. This could be accomplished through the Overseas Private Investment Corporation (OPIC), for example, and would allow Mexico to obtain needed infrastructure improvements in its petroleum industry while at the same time assist US manufacturers of heavy equipment.

Mexico could also attempt to incorporate US concerns into its energy planning and policies. One issue of concern to the United States is the environmental consequences of a major oil spill in the Gulf of Mexico, a concern that is certain to grow because much of Mexico's proven reserves are located in this region. Proven reserves in the Gulf are estimated to be 28.5 billion barrels of crude oil, 3.3 billion barrels of gas liquids and 12.4 trillion cubic feet of natural gas. The Gulf region contains 57 percent of total crude oil reserves, 46 percent of condensate reserves and 16 percent of natural gas reserves and will clearly figure prominently in future Mexican fossil-fuel development.

Uneasiness in the United States, particularly in the Gulf states, would be considerably eased if Mexican planners incorporated adequate safeguards against potential spills and accidents before major development projects are undertaken. If prior consultation with the United States took place, this would be viewed very favorably in the US and serve to further improve bilateral relations.

In fact, there already exists an informal, governmental working group to discuss bilateral energy-related issues between the United States and Mexico. The Bilateral Energy Consultation Group (BECG) was formed in 1982 and consists of representatives from the US Departments of Energy and State and Mexican counterparts from Ministry of Mines and Parastatal Industries. Meetings take place twice annually, in Washington and Mexico City, and could provide a forum to discuss some of the concepts previously discussed.

U.S.-MEXICO BORDER REGION

The border region between the two countries is a particularly sensitive area where the effects of energy and environmental policies are acutely felt. Issues related to air pollution, sewage treatment, water quality, shared energy resources and toxic waste disposal have a direct effect on the health and safety of residents in the border zone of the two countries. The issues related to border environmental concerns are both sources of tension and examples of cooperation.

An extensive literature exists that documents the many negative environmental consequences of development on both sides of the border. Less well known, and particularly relevant here, is the considerable progress that has been made in resolving transboundary environmental issues and the institutional structures that have been developed to deal with potentially conflictual situations. These institutional arrangements, both formal and informal, have helped to ease tensions and build confidence on both sides of the border.

One example of cooperative efforts is the signing in 1983 of the Border Environmental Cooperation Agreement between the United States and Mexico. This agreement, negotiated between the administrations of Presidents Reagan and de la Madrid, establishes a structural framework for regular meetings on environmental problems in the border region between the two states. A bilateral administrative mechanism was created to address border environmental concerns by designating the US Environmental Protection Agency (EPA) and the Mexican Secretariat of Urban Affairs and Ecology (SEDUE) as the lead agencies involved. These agencies are charged with monitoring whatever agreements are reached between the two governments regarding border environmental issues and are responsible for preparing an annual report to their respective governments on joint work conducted under the agreement.

Importantly, the 1983 agreement recognized that protecting the international border environment required coordination of national programs and policies. This concept provides the framework for coordinating national energy and environmental programs and policies to take into account concerns of a neighboring country and is a good example of using these policies to build confidence between states. Scientific and educational exchanges, environmental monitoring and information and data exchange are also covered in the agreement, which, when taken together, will assist in developing personal and institutional contacts that will also add to confidence building.

Some of the specific border environmental issues discussed under the agreement have been the sewage-treatment problem in the San Diego-Tijuana region, the degradation in air quality posed by smelter emissions along the Arizona-Sonora border and the issues surrounding the handling of hazardous materials in the border

region. Negotiations in each of these areas, although difficult and requiring considerable diplomatic skills, have been reasonably successful and progress has been made in dealing with these difficult bilateral issues.

FUTURE ISSUES IN THE U.S.-MEXICO BORDER REGION

Several problems related to energy and environmental projects and policies are likely to arise in the border region in the near future and need to be addressed. Some of these are:

- The continuing problem of sewage treatment in the San Diego-Tijuana area. The processing of sewage requires large amounts of energy and any cooperative solution to sewage treatment will probably involve some type of sharing of energy-related costs and/or energy resources.
- Development of energy resources in the border area. Significant regions of the border zone, particularly those with large urban populations like the San Diego-Tijuana region, are severely lacking in energy resources. There are no fossil fuels to speak of in these areas and the populations on both sides of the border are dependant on distant sources for their energy supply. Some sharing of energy resources presently takes place, as for example the transfer of electricity to Southern California from geothermal plants in Cerro Prieto, near Mexicali. As the region continues to grow, more effort should be made to develop joint projects that use energy resources indigenous to the border region, such as solar thermal and electric, geothermal and wind. Equally important, joint planning directed towards more efficient use of available energy resources, such as co-generation and off-peak utilization of electricity, could reduce the regions' dependence on fossil fuels.
- The availability of water, in sufficient quantity and quality has been, and will remain, a chronic problem and source of tension between the United States and Mexico. Associated with water supply is the related problem of energy to transport and treat the water. Where this energy will come from, how it will be allocated and how the costs will be distributed are problems that will require increasing attention in the years to come.

THE BALTIC REGION

The second case for which national energy and environmental policies have a profound effect on a shared regional resource is the Baltic Sea. This is a particularly important region because the Baltic is an area where security concerns of the two superpowers, as well as economic and security interests of their allies and of the neutral and nonaligned states, are brought into sharp focus.

The political alignments of the eight Baltic Sea States are quite complex. All are members of the United Nations, three are member states of North Atlantic Treaty Organization (West Germany, Denmark and Norway), three are of the Warsaw Treaty Organization (Soviet Union and Poland, East Germany), two are neutral (Sweden and Finland), four are in the Nordic Council (Sweden, Denmark, Norway and Finland), two are in the European Economic Commission (West Germany and Denmark), and three are members of the East European trading bloc, COMECON (Soviet Union, Poland and East Germany).

Despite the political complexities of the region and the long history of conflict between the Baltic Sea States, they all recognize that preserving the viability of the marine environment is vital to their own economic, political and security interests.

This recognition has provided the impetus behind a series of comprehensive agreements among the Baltic Sea States and provides, in many ways, a model of how cooperative measures designed to address serious environmental concerns can also build confidence between adversarial states.

By the late 1960s it was becoming apparent that increased pollution, much of it associated with energy-related activities, was resulting in serious deterioration of the Baltic marine ecosystems and that concerted action was required if irreversible damage to the Baltic was to be avoided. It was also recognized that the problems could not be solved by individual countries acting alone and that coordinated efforts by all the states that share the Baltic would be needed to guarantee comprehensive management and proper use of the natural resources of the Baltic.

To this end, the Finnish government invited all Baltic Sea States to participate in a conference on the protection of the Baltic marine environment. The conference, held in Helsinki in 1973, resulted in the Helsinki Convention, which was signed in 1974 by all states bordering the Baltic. The convention, which entered into force in 1980, created the Baltic Marine Environment Protection Commission with a permanent secretariat located in Helsinki.

The Convention is quite comprehensive and covers areas such as discharges from land-based sources, including airborne pollution, discharges from ships, dumping of wastes and international cooperation to combat oil spills. Significantly, the parties to the convention agreed to coordinate their policies for issuing permits to discharge harmful substances into the Baltic as well as to establish a coordinated Baltic Monitoring Program. The first stage of the monitoring program, begun in 1979 and ended in 1984, served as a pilot program with a limited number of stations and measurements. An expanded second stage, ending in 1989, will provide a more complete assessment of the state of the Baltic marine environment, and guidelines for future monitoring are now being developed. In addition to the ongoing monitoring program, periodic assessments of the state of the Baltic Sea are being carried out on a regular basis.

The institutional framework of the Helsinki Convention, the work of the Baltic Marine Environment Protection Commission, the monitoring and assessment programs, and the regular interaction and exchanges that these activities imply have all greatly assisted in easing tensions and enhancing cooperation in the Baltic region.

Another arena of cooperation between Baltic Sea states deals with combating acid rain. A particularly relevant example is the growing recognition in Sweden that it may be more economical to directly invest in pollution abatement equipment in Poland rather than in Sweden itself. Polish factories are one of the major sources of sulfur and nitrogen oxides in the region and because of the prevailing winds, much of the resulting acid precipitation falls on southern Sweden. Some recent calculations suggest that it would cost Sweden $66 million per year to reduce domestic emissions of sulfur and nitrogen oxides by 15 000 tons but that a similar investment in Poland would result in a reduction of one million tons. The Swedish investment would cover the hard currency portion of a comprehensive pollution control program cooperatively developed between Sweden and Poland.

CONCLUSION

National energy and environmental policies undoubtedly have major consequences beyond national boundaries. By entering into cooperative energy and environmental arrangements, which in many cases imply adjusting domestic practices, states can ease regional tensions. This, in turn, develops trust and

confidence between nations and enhances regional security. Two cases have been cited as examples: the United States and Mexico and the Baltic Sea States.

Further development of this concept requires detailed analysis of specific energy-related activities and how they could be modified to minimize regional effects. Such analysis is presently underway.

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ENVIRONMENTAL PERESTROIKA: ENERGY TECHNOLOGY AND EAST-WEST CONFIDENCE BUILDING

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INTRODUCTION

For the first time in history, human activities are affecting the Earth's environment so greatly that they threaten to trigger changes in the Earth's climate through a gradual warming of the atmosphere (the Greenhouse Effect). This process of global warming is the result of the combustion of fossil fuels, tropical deforestation, and other agricultural and industrial activities. By burning fossil fuels, every nation emits some portion of the "greenhouse gases" that contribute to global warming, and nearly every nation is likely to be adversely affected by the resulting changes to the Earth's climate.

The U.S. and the USSR are currently the largest contributors to the global warming problem, although Soviet energy consumption has been growing at a much greater rate than U.S. energy use, which has become far more efficient since 1973. It appears that both nations, and the rest of the world as well, stand to benefit from increased cooperation to alleviate this common environmental problem, principally through West-to-East technology transfer. Reducing global environmental threats, such as that of climate change, can significantly enhance the long-term national security of many nations, including the superpowers. Moreover, the international communication and cooperation that are required to implement these and other measures to protect the global environment provide an opportunity for East-West confidence building.

Emerging technologies, such as those that improve energy efficiency, can help reduce fossil-fuel use and alleviate the climate-change problem, and these technologies promise economic benefits as well. These technologies can reduce the capital demands of the Soviet energy sector, and they represent a potentially large market for international trade. Although environmental protection is conventionally thought to require economic sacrifice, this "win-win" situation provides an opportunity to pursue environmental and economic goals that are compatible and mutually beneficial.

GREENHOUSE-GAS EMISSIONS

Based on current emissions and rates of increase, carbon dioxide is projected to cause about 50 percent of potential global temperature increases over the next 40 years (Ramanathan, 1988). The remaining portion of the increase is expected to come from, in order of importance, methane, chlorofluorocarbons 11 and 12 (CFC-11 and CFC-12), nitrous oxide, and tropospheric ozone, although the potential contribution of the CFC's may be reduced if the Montreal Protocol successfully limits the production of these gases. With the exception of the CFC's, fossil-fuel use accounts for a large fraction of the worldwide anthropogenic emissions of all the principal greenhouse gases (U.S. DOE, 1988). Fossil-fuel combustion is by far the largest source of carbon-dioxide emissions, releasing almost 6 billion tons annually (Marland, et al., 1988).

The atmospheric concentration of carbon dioxide has already increased by 25 percent since 1900, committing the Earth's temperature to increase by approximately 1° C to its highest level in over 8000 years (Clark, 1982). Future emissions of carbon dioxide and other greenhouse gases could further commit the Earth's average temperature to increase by as much as 3° C in the next fifty years (Mintzer, 1987). The full extent of this temperature change would take place over decades, because the temperature effects are delayed by the huge thermal-storage mass of the oceans.

Although scientific evidence convincingly indicates that global warming will lead to severe ecological impacts, such as shifting rainfall patterns, expanding areas of desert, and a rising sea level, it is not known accurately when and where the impacts will occur and how severe the impacts will be. Although some regions of the world might benefit from a warmer equilibrium temperature, such rapid change is likely to have a negative effect on nearly every type of ecosystem and agricultural system (Ehrlich and Ehrlich, 1989). Thus, even regions that might welcome warmer equilibrium temperatures, such as northern Canada and Siberia, may not benefit from climatic change if it takes place at the expected rate.

The U.S. and the USSR produce disproportionately high per-capita emissions of all the greenhouse gases, especially those that are mostly from fossil fuels. The U.S., with 4.8 percent of the world's population, emits 24 percent of the world's fossil-fuel-based carbon dioxide. The USSR has 5.6 percent of the world's population and contributes 22 percent of the emissions (Marland, et al., 1988). These high relative rates of emission result from high rates of energy consumption and relatively heavy dependence on coal as a fuel. Because coal has a high carbon/hydrogen ratio, it releases more carbon dioxide per unit energy than other fuels (about 20 percent more than oil, and about 70 percent more than natural gas).

TRENDS IN THE INTERNATIONAL ENERGY ECONOMY

Over the last two decades, energy availability has had a tremendous impact on the economies of Western nations, from the shortages of the 1970s to the surpluses of the 1980s. When supplies were restricted during the 1970s, energy insecurity spawned action to address both sides of the energy pipeline: supply and demand. In the U.S., government support for research and development of new energy-supply technologies was stepped up, only to be reversed suddenly in the 1980s.

A special emphasis on energy efficiency and demand-side management eventually disproved conventional wisdom by showing that economic growth need not necessarily require commensurate growth in energy consumption. In fact, the U.S. economy grew by 35 percent between 1973 and 1986 with no increase in primary energy consumption. During this period, many Western nations also began to implement measures to address the growing consensus that unregulated fossil fuel consumption is causing substantial local and global environmental damage. The environmental costs of energy use, together with the recent resumption of U.S. energy growth, suggests the need for renewed policy measures to overcome low oil prices and public complacency regarding energy efficiency.

Energy plays a similarly important role in the planned economies of the USSR and its Eastern European allies. Since the Second World War, the Soviets have helped to sustain the economic progress of their allies by offering energy exports on favorable trade terms. Today, the Eastern European nations meet their energy needs by combining limited domestic resources with Soviet exports acquired by barter trade, a dependence that remains a key component of Soviet political influence in the region.

Petroleum has been more important to the Soviet economy than any other single commodity, and there is no reason to expect this trend to change in the near future. Energy exports to the West account for more

than half of Soviet hard-currency earnings. At the same time, primary oil production has moved from more accessible fields in western regions of the USSR to remote areas in Siberia, perhaps the world's richest storehouse of natural resources. More than 70 percent of the Soviet Union's known energy resources are in Siberia. Just two of its rivers, the Yenisey and the Lena, have greater hydroelectric energy potential than all U.S. rivers combined (WRI, 1988).

FUELING THE FIRES: SUPPLY-SIDE TRENDS

Between 1980 and 1986, total energy consumption increased more in the USSR than in any other nation, contributing fully 37 percent of the increase in world energy production (WRI, 1988). U.S. energy production during the same period declined by five percent. The Soviets lead the world in the production of both oil and natural gas, followed by the U.S. in both cases. Soviet coal production is third in the world, after China and the U.S.

Growth in Soviet oil production slowed, however, between 1975 and 1983, and then declined in 1984–1985. Then in 1986, and again in 1987, output reached record levels as a result of heavy investment in the oil sector. While the USSR is the world's largest oil producer (and a net exporter), the U.S. is the world's largest consumer and importer of oil (British Petroleum, 1988). Oil production in the contiguous 48 states has been declining since 1970; overall, U.S. oil production has never surpassed its 1970 level. Soviet gas production in 1987 continued a steady rise, surpassing oil production (in energy-equivalent terms) for the second consecutive year. U.S. gas production, like that of oil, has fluctuated during the last decade, without any large increase.

The U.S. and the USSR each possess about one-quarter of known global coal reserves, and together with China and Eastern Europe, these nations hold about 75 percent of the known reserves (see Table 1). The U.S. produced 20 percent of the world's coal in 1987, the USSR 16 percent, and China 24 percent (British Petroleum, 1988).

Because of their large coal reserves, the Soviet Union and China will probably play an increasingly important role in the global warming problem. As a relatively abundant and cheaply accessible fuel, coal will be an attractive source of energy for these nations, which are undergoing rapid industrial development. Moreover, the industrial base in the Eastern Bloc nations is far more concentrated and rapidly growing in the heavily energy-intensive process industries than in the West (Hewett, 1984). If their energy consumption continues to grow at current rates, especially if fueled predominantly by coal, the carbon dioxide concentration of the atmosphere will increase dramatically. Thus, energy consumption growth in the Eastern Bloc will have a major influence on the world's climate.

As mentioned above, world carbon dioxide emissions are distributed very unequally at present, with the U.S. and the USSR the largest contributors. Projecting recent trends in world fossil-fuel carbon emissions forward to 2020 suggests that the U.S.S.R. and China will become the largest sources of carbon, with the other developing nations contributing an increasing share as well (see Table 1).

TABLE 1. WORLD CARBON EMISSIONS (million tons per year)

	Tropical Deforestation 1986-actual	Fossil Fuels 1986-actual	Fossil Fuels 2020-projected	Coal Reserves (% of World Total)
USA/Canada		1500 (27%)	1900 (14%)	26%
Other OECD		1100 (20%)	1600 (12%)	16%
USSR/E. Europe		1500 (27%)	3900 (30%)	32%
China		600 (10%)	2300 (18%)	17%
Other Asia	400	500 (8%)	1900 (14%)	2%
Latin America	700	300 (5%)	800 (6%)	1%
Africa	400	200 (3%)	800 (6%)	6%
World Total	1500	5600 (100%)	13200 (100%)	100%

Projections based on 1973-1984 growth rates in per capita carbon emissions and population projections from the Population Reference Bureau.

Sources: Marland, et al., 1988; British Petroleum, 1988; WRI, 1988; Sathaye, et al., 1987; PRB, 1988.

SPINNING THE WHEELS: THE NEED FOR DEMAND-SIDE EFFICIENCY

The Soviet government is beginning to face both domestic and international pressure regarding energy-related environmental problems, especially those related to coal burning and nuclear power. Considering the potential Eastern Bloc contribution to global warming, it seems to be in the best interests of the Western nations, for both environmental and security reasons, to seek ways to improve the efficiency of energy end-use technology in the USSR and other Eastern Bloc nations.

Although the latest Soviet Five-Year Plan calls for an emphasis on energy efficiency and conservation, increasing supplies appears to remain the key investment to meet increased energy demand. Meeting their projections for energy supply growth would require committing two-thirds of the incremental national capital investment to building energy facilities. They have recognized that this is not feasible and that energy efficiency can provide energy services at one-third to one-half the cost of equivalent fuel or electricity supplies (Sagers, 1985). However, there has been little success in implementing efficiency measures.

A simple measure of national energy efficiency is total energy consumption per unit of GNP. Although it is difficult to obtain comparable GNP data for planned economies, Soviet energy use per unit of GNP is estimated to be approximately twice that of the U.S. and three times that of Japan or Sweden (Chandler, 1987). More importantly, while the Western nations have become more energy-efficient every year, the Eastern Bloc nations show little evidence of improved energy efficiency (Hewett, 1984). In the USSR, heating energy use, per square meter of building floor area, has been increasing in recent years (Sagers, 1985).

Some of this discrepancy can be attributed to the greater concentration of the Soviet economy in the heavily energy-intensive process industries. However, much of the Soviet energy growth appears to be the result of failure to implement the technical efficiency improvements that have been successful in the West. The lack of a competitive pricing structure and heavy subsidies for residential energy use prevent the sort of market response to energy prices that has stimulated energy efficiency improvements in the West. However,

it appears that a more basic problem is simply that the Soviet Union has not developed energy efficiency or renewable energy technology as quickly as the OECD nations. Moreover, energy-saving products that have been developed are often in such short supply that they cannot be widely used (Sagers, 1985).

This technical gap is especially apparent in regard to building energy efficiency. Heating, lighting, and refrigeration efficiencies are each at least 40 percent more efficient in the OECD nations than in the Soviet Union (Hewett, 1984, Sagers, 1985 and WRI, 1988). Many energy-saving technologies are available in the buildings sector, including improved insulation, glazing materials, lighting equipment, refrigerators, motors, and controls. Moreover, building energy analysis and design techniques make it possible to utilize passive solar heating and/or daylighting, such that properly designed buildings essentially heat and light themselves.

Implementation of these technologies in the Soviet Union requires several tools: 1) adaptation of state-of-the-art energy analysis and design techniques to the Soviet climate and building practice, 2) planning and pricing strategies, appropriate to a centrally-planned economy, to facilitate the use of energy-efficient technologies, 3) utility systems planning to accommodate load management and small-scale renewable energy systems, 4) increased availability of energy-efficient products, facilitated by joint ventures between Soviet enterprises and Western firms, and 5) methods for measuring and assigning values to environmental costs and including these costs in planning work.

OPPORTUNITIES FOR ENERGY EFFICIENCY AND RENEWABLE RESOURCES

The technical solutions to reducing energy consumption can be as simple as ceiling insulation and efficient fluorescent lighting hardware. However, there are also a number of new and advanced technologies, ranging from high-performance windows to electronic control devices, that have only recently become available and that promise significant efficiency gains compared to current practice. New renewable-energy technologies also show great promise in relieving the demand for fossil fuels.

Simple weatherization and insulation can reduce heating needs in existing homes by 25 to 50 percent. Of course, this level of savings and more are cheaper and easier to achieve in newly constructed buildings. Passive solar houses, which are designed to heat themselves by collecting and storing solar energy, have been extensively tested in the U.S. and shown to save 75 to 90 percent of the energy used by typical existing houses (Swisher, et al., 1983). New insulating window materials are being developed and are beginning to reach Western markets. These products have the potential to make almost any well-insulated house nearly self-sufficient in heating. Moreover, efficient appliances such as water heaters, refrigerators, and air conditioners can save electricity more cheaply than it can be generated by new power plants.

Commercial and institutional buildings present even more attractive energy-saving opportunities. Incandescent lights can be replaced by fluorescents that are four times more efficient with no net cost because the fluorescents last several times longer. Standard fluorescent lamps, ballasts and fixtures can be replaced by high-efficiency lamps, electronic ballasts, and specular imaging luminaires to achieve about 60% savings at a cost of about 2 cents/kWh in the U.S. In new buildings and in existing buildings with large areas near perimeter windows, the lighting controls can be designed or modified to reduce electric lighting levels in response to natural daylight, achieving similar cost-effective savings (Robbins, et al., 1985).

These types of building-energy savings are some of the least expensive energy investments available today worldwide. Many U.S. communities and energy utilities have a wide variety of programs to encourage energy improvements in existing buildings and efficient designs of new buildings. These programs include financial incentives, education programs, energy-rating systems, building codes, and performance standards.

In support of these programs, there has been a great deal of work in the U.S. to determine "supply curves" for energy efficiency. A study for the East Central region of the U.S. found that 48 percent of residential, 35 percent of commercial, and 20 percent of industrial electricity use could be saved without increasing total customer costs, providing a significant reduction in sulphur emissions that are blamed for the acid rain problem in that region (Geller, et al., 1987). These measures are equally effective in reducing carbon dioxide emissions.

Industrial energy efficiency in the West has been increasing every year since even before the oil crises. New processes and greater use of electronic controls and waste-heat recovery continue to reduce industrial energy intensity (Williams, et al, 1987). Industrial energy use can be improved further, especially in regard to electricity use. The largest industrial-electricity use worldwide is to run motors. There is currently a quiet revolution underway in the power electronics field, where new products include more efficient motors and improved electronic motor controls, which provide better matching of motor speed to loads and therefore higher energy efficiency (EPRI, 1988). Although these are rather small changes, high-efficiency adjustable-speed motors can potentially reduce industrial electricity use by 30 to 50 percent.

Of the many renewable energy technologies, perhaps the most promising is solar photovoltaics. These semiconductor devices, which convert sunlight directly to electricity, were invented for the U.S. space program in the 1950s. Since then, the cost of photovoltaics has fallen from hundreds of dollars per kilowatt to about five dollars per kilowatt, very close to being commercially competitive in some applications. There are numerous individual photovoltaic materials under development, each with promise for providing inexpensive power for both remote and utility grid-connected applications. The simplicity and decentralized nature of photovoltaics make them especially attractive in the short term for remote power projects.

There is great potential for providing direct heat and light and electricity generation from a variety of renewable sources. None of the individual options alone provides a panacea for solving national or world energy problems. However, if properly matched to local climates and energy needs (which can and should be reduced by energy efficiency measures), these technologies together provide an environmentally attractive alternative to fossil fuels.

THE SECURITY CONNECTION

The global nature of the energy-climate interactions creates strong connections with national-security issues. The energy-security connection begins with the continuing tension in the Persian Gulf. Because U.S. domestic oil production has been falling, U.S. reliance on Middle East oil supplies is increasing. The current military tensions in that area can only become more precarious as more nations demand more oil from the Gulf. The Soviet Union is currently an oil exporter, providing Eastern Europe's oil and exporting small amounts to the West in exchange for hard currency. However, recent estimates indicate that Soviet oil production may soon peak and begin to decline (British Petroleum, 1986). As a result, Eastern Europe and eventually the Soviet Union itself may turn to the Middle East for their fuel supply. East-West competition over oil supplies in the Middle East would only complicate and aggravate the already tense military situation in the Persian Gulf.

The Soviet Union, with its energy-intensive economy and large coal reserves, will likely be the most important nation in determining the future direction of global warming and other environmental issues related to fossil fuel use. From an international perspective, continued growth in fossil-fuel consumption

between East and West. Energy efficiency and renewable energy technology may be a promising area for Western firms to enter joint ventures for production in the Soviet Union. In the short term, exporting energy-efficient products to the Eastern Bloc would increase the market for these products and improve the economic efficiency of the energy sector in these nations. In the longer term, the most important effect would likely be the global environmental benefits of reduced Soviet energy consumption.

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could lead to dangerous international threats, in that regional instabilities caused by climatic change or by declining fuel supplies could develop into international conflicts.

Throughout history nations have gone to war over natural-resource disputes. The international effects of climate change caused by fossil fuel combustion could become severe enough to threaten military security in hard-hit nations, desperate to replace their lost agricultural or industrial resources. In light of these risks, it is not an exaggeration to say that environmental dangers could begin to transcend the traditional East-West military rivalries.

Additional sources of global insecurity appear in the Third World, where growing energy demands have imposed constraints on development and political stability. The major economic constraints include foreign-exchange demands for imported oil and capital demands for developing energy production and distribution facilities. The worst effect of the oil price increases of the 1970s was to price the developing nations, most of whom have minimal domestic oil reserves, out of the world oil market. These nations were forced to choose between bidding against the more affluent nations or accelerating the development of domestic sources of energy. The latter choice often placed excessive demands on investment capital and contributed to the debt crisis in developing nations, many of whom spend more than 30 percent of their entire development budget on energy (US AID, 1986).

Already deforestation and other forms of environmental damage have caused military tensions among developing nations. For example, military conflict between Ethiopia and Somalia, partially financed by both superpowers, was the direct result of deforestation in the Ethiopian highlands. The total military expenditures were several times greater than the United Nations estimate of the cost of reforestation. In many nations, the diversion of funds from military preparations to environmental restoration efforts, such as reforestation and improving energy efficiency, may provide more true security, in economic and environmental terms, than additions to military arsenals (WCED, 1987).

OPPORTUNITIES FOR COOPERATION AND COLLABORATION

International discussion of environmental problems is becoming increasingly necessary to avert environmental crises, such as that threatened by global climate change. At the same time, this discussion provides an important arena in which to expand and improve East-West and North-South cooperation. The recent improvement in East-West relations presents an opportunity to pursue new agreements regarding environmental initiatives such as climate protection.

Such agreements could provide significant international security benefits by reducing global environmental risks and by facilitating international communication, cooperation, and peace-keeping. By bringing nations to the bargaining table to discuss otherwise intractable problems of the global commons, the global climate-change issue could become a catalyst for improving international trust and security.

The U.S. and USSR have already entered several bilateral and multilateral fora that are concerned with global climate change. Bilateral cooperation in the field of environmental protection began in 1972 and has recently focused on climate effects. The Intergovernmental Panel on Climate Change, convened by the United Nations Environment Programme and the World Meteorological Organization, has established three working groups on global climate change. The U.K. chairs the basic science group, the USSR chairs the group studying the effects of climate change, and the U.S. chairs the policy response group.

International trade will also play an important role in the future of the global environment. The advent of perestroika in the Soviet Union has created new opportunities for trade and technical cooperation

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INTERNATIONAL CARBON EMISSION OFFSETS: A TRADEABLE CURRENCY FOR CLIMATE PROTECTION SERVICES

by

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INTRODUCTION

Reversing the trend of tropical deforestation would provide many ecological benefits, including slowing the rate of global climate change, which is being caused in large part by carbon-dioxide emissions from fossil-fuel use. While the responsibility, the technology, and the financial resources for reducing carbon emissions are all concentrated in the industrialized nations, much of the potential for reducing future emissions is in the developing nations. Thus, successful solutions to the climate problem will likely require significant transfers of resources, including debt relief, from North to South.

If one or more industrialized nations agree to reduce their contribution to global carbon emissions, these nations will need to adopt policies to achieve the reductions. Market-based policies, such as carbon-emission taxes or tradeable emission permits, would assign a monetary value to reducing atmospheric carbon. Similarly, an international market mechanism for trading climate protection services worldwide would impart this value to investments in measures such as afforestation or energy efficiency, allowing carbon emitters to seek the least expensive ways to reduce emissions.

International carbon-emission offsets (ICEOs) could provide such a mechanism, by creating a currency for investing in carbon-saving services as a way to comply with national policies to reduce carbon emissions. The opportunity to sell these services as ICEOs, or to trade them for debt relief, would give the developing nations a tangible economic incentive to use clean energy technologies and to protect their forests, rather than to deplete them. For example, instead of having to choose between economic development and environmental protection, Third World nations would find themselves endowed with a valuable export commodity in the environmental services from their forested or potentially-forested lands.

A full-scale market in environmental services could take advantage of the following economic and policy mechanisms, which will be discussed in more detail later:

- An international agreement (preferably a climate-protection treaty) that sets a goal for the reduction of carbon emissions (globally and for individual nations) and formalizes cooperation in an environmental market program;
- A system of tradeable international carbon-emission offsets (ICEOs), with which the holder, by reducing carbon emissions anywhere in the world, can comply with its country's climate policy, such as a carbon tax or an emission ceiling;
- A market for carbon-saving projects, such as afforestation or energy efficiency, valued according to the equivalent quantity of carbon dioxide they save or replace;
- A set of incentives for forgiving Third World debt in exchange for commitments to reforestation or other carbon-saving projects.

BACKGROUND

By burning fossil fuels, every nation emits some portion of the carbon dioxide and other trace gases that contribute to global warming (the Greenhouse Effect), and nearly every nation is likely to be adversely affected by the resulting changes to the Earth's climate.[1] While scientific evidence convincingly indicates that global warming will lead to severe ecological impacts, such as shifting rainfall patterns, expanding areas of desert, and a rising sea level, it is not known accurately when or where these impacts may occur and how severe the impacts will be.[2]

Worldwide emissions of carbon dioxide, the cause of more than half of the global warming, are not distributed equally at present. Approximately 80 percent of total emissions come from fossil fuels, mostly from industrialized nations. Most of the remaining 20 percent comes from deforestation, mostly in tropical developing nations. The U.S. and the U.S.S.R. are the largest contributors, together emitting nearly half of the world's carbon from fossil fuels. Brazil is the largest contributor of carbon from deforestation, with approximately 20 percent of the world's biological carbon emissions.[3]

In the future, the Eastern Bloc and developing nations will probably play an increasingly important role in the global warming problem and thus cannot be ignored in any strategy to solve the problem.[4] Technological advances, if applied only in the Western industrialized nations, will not be sufficient to protect the Earth's climate. It therefore appears that new economic initiatives, backed by strong national policies and international agreements, are needed to implement the measures that can alleviate global warming.

TOWARD A CLIMATE-PROTECTION TREATY

The very fact that alleviating the global warming problem requires international cooperation might make the prospects for solutions seem remote, given the history of such efforts. However, there are clear precedents for international negotiation in the area of global environmental protection. For example, the signing in 1987 of the Montreal Protocol, a twenty-four-nation agreement on the regulation of chlorofluorocarbons (CFC's), which contribute to global warming and endanger the Earth's atmospheric ozone layer, indicates potential for improved international cooperation regarding environmental and resource issues.

An international treaty to limit emissions of greenhouse gases would provide a timetable for the implementation of low-carbon policies and incentives at the national level. Through either a multilateral treaty, bilateral agreements, or unilateral action, assigning target levels of carbon emissions to individual nations would give each nation the responsibility for finding ways to reduce its carbon emissions. For the developing nations that are not currently major carbon emitters, the treaty would formalize their participation in international economic mechanisms that help achieve the agreed-upon reductions.

Several international bodies have already proposed various types of agreements concerning greenhouse gases. In June 1988, the World Conference on the Changing Atmosphere called for a strengthening of the Montreal Protocol limiting CFC production and a 20 percent reduction in global carbon dioxide emissions by the year 2005.[5] Since mid-1988, several bills have been introduced in both houses of the U.S. Congress to enact similar goals for the U.S.

If the U.S. were to reduce its carbon emissions by 20 percent in less than 20 years, in accordance with the proposed legislation, it would require a dramatic shift in energy policy. Although this goal is technically feasible with the energy efficiency technologies now becoming available, the implementation of these measures would be difficult and would certainly entail significant changes in the energy economy.

Fortunately, many of these technologies appear highly cost effective, compared to new sources of energy supply.[6] Thus, a transition to a low-carbon energy future need not entail economic hardship.[7] In fact, the U.S. economy grew by 35 percent between 1973 and 1986 with no increase in primary energy consumption.[8]

INTERNATIONAL CARBON EMISSION OFFSETS (ICEOs)

The World Conference on the Changing Atmosphere also called for a world fund for atmospheric stabilization, financed in part by taxes on fossil-fuel use in industrialized nations, to promote conservation in developing nations.[5] A market-based approach such as ICEOs could distribute the burden and the benefits of climate protection in a similar way, and it could be implemented incrementally, starting with a few nations, rather than requiring a new international bureaucracy. An ICEO program could be overseen by the U.N. or the World Bank for the sake of score-keeping and compliance, but it would not require a central institution to administer the transactions. This simplification would reduce the scope of international agreements that would be necessary to implement such a program.

Tradeable emission offsets have been used by the U.S. Environmental Protection Agency (EPA) as a market mechanism for reducing the cost of compliance with the Clean Air Act. In some regions, new pollution sources must reduce total emissions by more than the amount of pollution that they will emit, using emission offsets obtained by paying to install better emission controls on other sources. Existing sources can also trade emission permits within a local air quality "bubble." Simulation studies have shown that the costs of existing emission-control regulations are two to six times greater than efficient market mechanisms.[9]

Carbon dioxide is not a local pollution problem; only the global concentration matters. Thus, we propose to apply tradeable offsets internationally, extending the air quality "bubble" to the entire atmosphere of the Earth. Instead of requiring a firm to reduce or replace its own emissions directly, tradeable ICEOs would provide the firm with a currency to invest in cost-effective energy efficiency or afforestation projects, even if they invest in another country. This currency would assign a market value to all carbon-saving services, enlarging the range of options available to those charged with reducing emissions. Regulatory standards and other market mechanisms, such as emission taxes, are less flexible when they can only be applied within a nation. Emission taxes, however, could be more efficient if firms are allowed to credit ICEOs against their emission tax.

A system of tradeable ICEOs would not require that individual nations use tradeable offsets to enforce their own emission-reduction policies. Different nations could use any performance-based or market-based approach, including an emission ceiling, a carbon dioxide tax, or other policies. The essential prerequisite for an ICEO system is that individual nations allow investments that reduce carbon emissions in other countries to comply with their own national policies.

CARBON-SAVING SERVICES

Because tropical forests play a crucial role in the Earth's carbon balance, they provide an essential carbon-saving service. Under a system of ICEOs, each hectare of forested land, or land that can potentially be reforested, could provide a valuable environmental service to customers anywhere in the world.

This opportunity has already been explored by a U.S. electric power company that invested $US 2 million in a project that will plant 52 million trees in Guatemala. The trees will absorb as much carbon as the company's new 180,000 kilowatt power plant will produce in 40 years.[10] The tree-planting project added less than one percent to the cost of the power plant, although the company's cash investment will be supplemented by $US 14 million in in-kind services from U.S., Guatemalan, and international organizations. If the value of these services were added to the company's cost, the total would still be less than 10 percent of the total plant cost.

Carbon-saving services need not be forest projects. As suggested earlier, energy-efficiency projects would be attractive to those seeking ICEOs. They could also invest in renewable or nuclear-energy projects, which produce no carbon dioxide. Investments in these energy projects would qualify for carbon-emission offsets in proportion to the carbon-equivalent of the energy saved or produced. For a given energy project, the allocation of emission-offset credit to the project owner and the outside investor would be a matter of negotiation between the parties. Also, emission-offset credit could be distributed as part of the ownership rights to shareholders in an individual project. The opposing interests of the various parties would create price competition and help to identify and finance the most cost-effective carbon-saving projects.

DEBT-FOR-NATURE TRADES

The Third World debt crisis has spawned a secondary market for unpaid foreign debts. These debts may now be exchanged, at a substantial discount, for equity or investment privileges in the debtor nations. Although this process has the effect of increasing foreign influence in Third-World economies, it provides a precedent for a much more promising type of debt-swapping process: debt-for-nature trades.

Under this scheme, conservation organizations buy the discounted debt and then trade it to the debtor government, not for equity, but for the right to manage forest lands, financed by interest-bearing bonds in local currency. The conservation organization can be foreign, domestic, or a combination. In fact, each of these three possibilities has already worked successfully, although the capital to buy the debt must ordinarily come from outside the debtor nation.[11]

The debt-for-nature process provides multiple benefits: 1) the debtor nation internalizes some of its foreign debt, saving precious foreign currency, 2) the foreign banks receive the market value of the bad debt and write off the remainder as a business loss, 3) funds become available for investments in conservation and reforestation, 4) the use of these funds provides economic and employment opportunities in protecting, rather than destroying, forests, and 5) protected forest reserves and parks provide opportunities for increasing foreign exchange through tourism.

Several debt-for-nature trades have already been accomplished. The first was engineered in 1987 by a U.S. conservation group that used private donations to purchase $US 650,000 in discounted Bolivian debt and exchanged the debt for a commitment to protect 1.5 million hectares of forest land.[12] The government of Ecuador has offered interest-bearing local-currency bonds to fund conservation projects in exchange for up to $US 10 million in external debt. This project was implemented entirely by an indigenous, non-governmental organization.[13] In Costa Rica, the government traded local-currency bonds to international conservation groups in exchange for $US 1.5 million in discounted debt.[12] The groups use the interest from the bonds to buy land and equipment and pay for personnel and expenses to manage forest reserves and begin reforestation work. The government plans to expand this program to $US 70 million worth of debt-trades in the near future.[14]

PUTTING THE PIECES TOGETHER

Each of the mechanisms described above can contribute to alleviating the problem of global climate change. While each component can operate alone in a specific policy context, assembling the different components together, under the policy umbrella of a multilateral treaty for the reduction of carbon emissions, would provide a set of economic and policy tools for rewarding actions that protect the Earth's climate.

An example of the application of these mechanisms would be a situation in which (see Figure 1):

- Under the terms of an international climate-protection treaty, a nation enacts legislation that requires a specified reduction in total carbon emissions;
- Power plant owners in this nation are required to reduce carbon emissions by some fraction to comply with the law and the treaty, or else pay a tax or penalty;
- Rather than pay the tax or penalty, they purchase ICEOs from an international broker;
- The broker arranges for investment in its own or another country's reforestation, renewable energy, or other project that reduces the carbon load on the atmosphere, in exchange for debt relief, cash, or other instruments;
- By dealing with a bank holding unpaid Third World debts, the broker is able to reduce the cost of the ICEO by leveraging a greater amount of investment (in local currency) than by dealing strictly in foreign exchange; and
- The recipient nation benefits from the conservation project and complies (in part) with the treaty through participation in the transaction.

THE DEVELOPMENT CONNECTION

Under existing conditions, most developing nations face strong pressures to pollute and deplete their natural resources. Increasing industrialization and urbanization, together with rising living standards, create greater demands for energy.[15] At the same time, the greatest threat to remaining tropical forests is the poverty of growing rural populations in the Third World. Without sufficient jobs or land to grow food, they have little choice but to clear forests in an effort to maintain a subsistence standard of living.[3,16]

Debt-for-nature trades provide a crucial mechanism for relieving the pressure of foreign debt on the natural resources of developing nations. According to Dr. Alvaro Uma$a, Minister of Natural Resources, Energy and Mines in Costa Rica, debt trades provide the only available incentives for protecting and enlarging forest habitats. Unfortunately, the limited resources of the international conservation community can never be sufficient to protect and reforest a large fraction of the world's tropical forest land.[14]

A much larger source of capital, however, could be the carbon emitters of the industrialized world. ICEOs would give them an incentive to seek carbon offsets by investing in discounted Third-World debt and exchanging this debt for carbon-saving through forest conservation and reforestation. We recommend that ICEOs and other market-based mechanisms be considered in the continuing debate and negotiations regarding measures to protect the Earth's climate.

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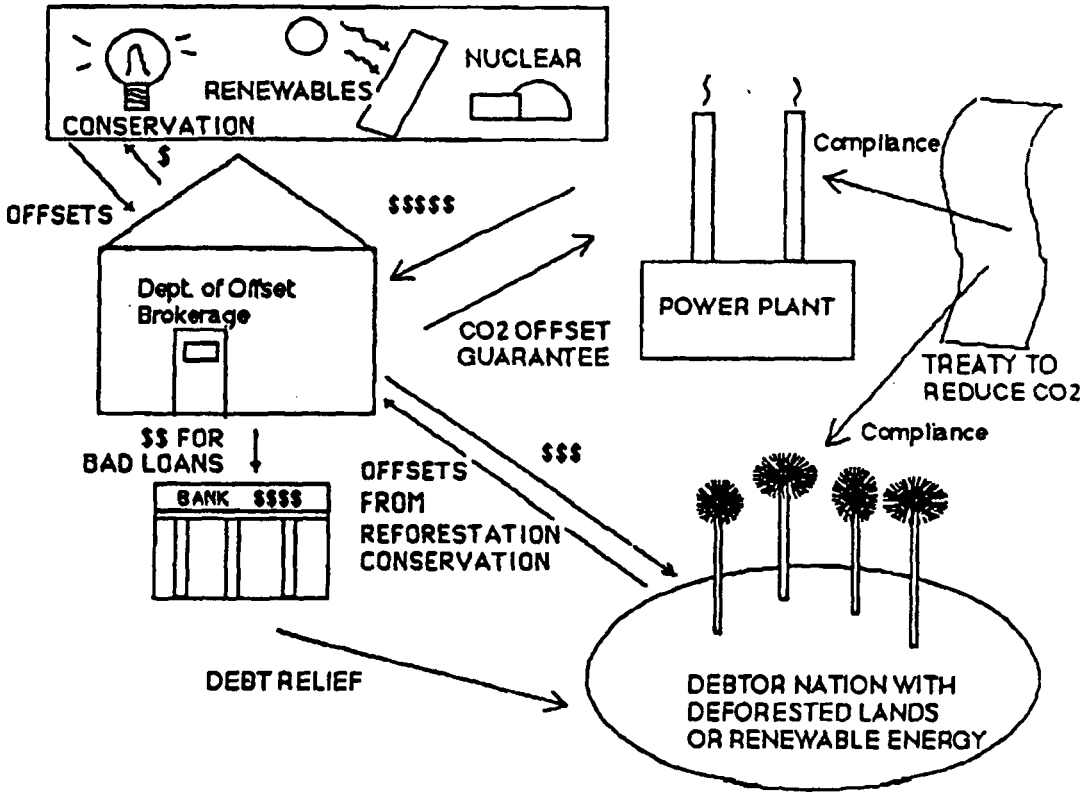


Figure 1. See text.

US DEPARTMENT OF THE INTERIOR
INTERNATIONAL COOPERATIVE RESEARCH ACTIVITIES

by

Dr. Harlan L. Watson
Science Advisor to the Secretary of the Interior
Deputy Assistant Secretary for Water and Science

I am pleased to have the opportunity to be here in Santa Fe to represent Secretary of the Interior Manuel Lujan, Jr. at the Conference on Technology-Based Confidence Building: Energy and Environment.

As many of you know, during his 20 years in Congress, Secretary Lujan was a strong supporter of science and technology in general and international cooperation in science and technology in particular. He shares the view of Louis Rosen and the other organizers of this conference of the importance of focusing attention on major global concerns, such as energy and the environment, and encouraging international cooperative activities toward addressing these concerns.

Let me first take a few minutes to acquaint you with the scope and structure of the US Department of the Interior.

The Department has an annual budget of about $6 billion and is the Federal Government's largest landowner: approximately one-fourth of the Nation's land mass is owned and managed by the Department.

Interior might best be described as a holding company composed of 10 small corporations—or agencies—which, in one way or another, impact the lives of nearly every American on a daily basis:

- **The Bureau of Indian Affairs** is responsible for managing and protecting natural resources on 52 million acres of Indian trust lands and for assisting tribes to serve nearly 865 000 American Indians and Alaskan Natives.
- **The Bureau of Land Management** is responsible for the multiple-use management of natural resources on approximately 270 million acres of public lands in 30 States, including 90 million acres in Alaska. These lands are used for grazing, oil and gas production, mining, timber, and recreation.
- **The Bureau of Mines** provides information and conducts research to ensure that the Nation has an adequate and dependable supply of minerals to meet its defense, economic, social, and environmental goals.
- **The Bureau of Reclamation** supplies municipal water to some 25 million people in 17 western states; provides irrigation water for 10 million acres of farmland in these states; and operates 51 hydroelectric facilities which generate about 48 billion kilowatt hours of electricity annually.
- **The Fish and Wildlife Service** manages 445 national wildlife refuges and 28 wetland management districts covering about 90 million acres. In addition, the Service manages 71 fish hatcheries throughout the country.
- **The Minerals Management Service** has dual responsibility both to collect and disburse revenues collected from mineral leases on Federal and Indian lands and to oversee the orderly development of the Nation's offshore energy and mineral resources. The Service also conducts extensive research on offshore environments.

- **The National Park Service** manages 354 areas which covers nearly 80 million acres in 49 States, the District of Columbia, the Virgin Islands, Guam and the Northern Mariana Islands.
- **The Office of Surface Mining, Reclamation, and Enforcement** oversees state programs that regulate surface mining and provide grants to states to reclaim surface-mined lands.
- **The Office of Territorial and International Affairs** carries out the Secretary's responsibilities with respect to the US Territories of Guam, American Samoa and the Virgin Islands, the Commonwealth of the Northern Mariana Islands, the Trust Territory of Palau, as well as the new Freely Associated States of the Federated States of Micronesia and the Republic of the Marshall Islands.
- **The US Geological Survey** is the Nation's premier mapping, geological, and water research agency. Much of its research is conducted cooperatively with other federal agencies, state and local governments, and universities. For example, the Survey assesses the quantity, quality, and use of water in cooperation with over 1000 state and local agencies in 50 States and the Territories.

The Department of the Interior's broad responsibilities make it a major player in natural resource policies—agriculture, economics, energy, the environment, and water. The Department's constituencies are broad and varied and are often in conflict with one another.

But the Department's great diversity is also its great strength, and the problems and concerns of the Department have much in common with the problems and concerns faced by many of the nations of the world. Similarly, the scientific and technological research conducted by the Department offers great opportunities for collaboration with all nations of the world.

Clearly, global climate change is of great concern to the Interior Department. Dallas Peck, the Director of the US Geological Survey, chairs the Office of Science and Technology Policy's Committee on Earth Sciences, and I currently represent the Department on that Committee. The Department carries out significant global-change research programs, and many of these programs will offer significant opportunities for international collaboration.

I also want to share with you other opportunities for scientific and technological cooperation that two agencies within the Interior—the US Geological Survey and the Bureau of Reclamation—are currently pursuing with the Soviet Union.

One of the areas of opportunity for scientific collaboration with the Soviet Union is geoscience. On January 8, 1989, after almost two years of negotiation, Secretary of State Schultz and Soviet Foreign Minister Shevardnadze signed an Agreement on Cooperation in the Field of Basic Scientific Research, which establishes a general framework at the agency level for US-Soviet research programs of mutual interest. On May 8, 1989, Erich Block, Director of the National Science Foundation, and Dallas Peck, Director of the US Geological Survey, signed two Memoranda of Understanding (MOU), which represent the first operational implementation of this Agreement.

These MOU's are between: 1) the National Science Foundation and the Academy of Sciences of the Soviet Union; and 2) the US Geological Survey and the Minister of Geology in the Soviet Union. The Soviet Academy of Sciences and the National Science Foundation are also specified as participating organizations under the US Geological Survey MOU and will have coordinators who serve as the principal point of contact for their organizations.

The Basic Science Agreement and the subordinate MOU's explicitly address cooperation in basic—as opposed to applied—research. The US Geological Survey-Minister of Geology MOU is specifically directed towards cooperation in the geosciences. In addition to substantial geoscience components, the

National Science Foundation-Academy of Sciences MOU also provides for cooperation in the areas of mathematics, theoretical physics, chemistry, life sciences, basic engineering research, scientific problems of the Arctic and the North, and science policy.

The participation of the National Science Foundation and the US Geological Survey on the US side, and the Academy of Sciences and Ministry of Geology on the Soviet side, will provide for access to a broad range of geoscience research facilities. As a general rule, the US academic research community will be served through the National Science Foundation-Soviet Academy program, and the US Geological Survey-initiated research proposals will be coordinated through the USGS-Ministry of Geology MOU.

A number of topics are currently being discussed for possible proposals under the USGS-Ministry of Geology MOU. These include cooperative studies of US and Soviet mineral deposits, various studies involving Soviet superdeep drill holes, a comparison of oil and gas resource assessment techniques, and the use of data bases for mineral resource assessment.

The 28th International Geological Congress, taking place in Washington from July 9th through the 19th, will provide one of the first major opportunities for discussion of possible cooperation under the NSF and USGS MOU's. Members of the Soviet Ministry of Geology and the Soviet Academy of Sciences will be meeting with US geoscientists to discuss potential joint projects.

Also within the Interior Department, the Bureau of Reclamation has undertaken joint ventures with the Soviet Union. During the 1970's, through the Joint Working Group on Cooperation in the Field of Water Resources, the Bureau of Reclamation and the Soviet Union collaborated in several areas, and these collaborations led to numerous exchanges of personnel between the US and the Soviet Union and to the publication of a number of joint scientific papers.

Earlier this year, the Soviet Embassy in Washington approached the Bureau of Reclamation regarding the possibility of initiating a science and technology agreement between the two countries. Discussions are currently underway on a number of topics of mutual interest, and it is hoped that some joint projects can be initiated within the next year.

This concludes my discussion of the Department of the Interior's collaboration research efforts with the Soviet Union. The Department will be exploring these and other collaboration opportunities with the international science and technology community.

Again, on behalf of Secretary Lujan, I want to thank you for the opportunity to be here today and to share with you the Secretary's hope that this and other future conferences will benefit scientific and technological cooperation among all nations of the world to address global problems.

Thank you.

NUCLEAR ENERGY, CARBON DIOXIDE, AND INTERNATIONAL COOPERATION

by

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The greenhouse effect provides a powerful incentive to develop and deploy energy technologies that emit less carbon dioxide (CO_2) than do conventional fossil fuels. To be sure, controversy still surrounds the greenhouse effect: how large is the warming, when might the warning occur, how will the warming affect the distribution of rainfall and other weather patters. One proposition, however, is incontrovertible: the amount of CO_2 in the atmosphere has been increasing at the rate of about 1 part per million per year (i.e., about 3 gigatons carbon/yr, GTC/y) ever since accurate measurements became available in 1958 and now stands at about 350 ppm. This corresponds to about 750 gigatons (billion tons) of carbon (as CO_2) in the atmosphere.

A second proposition, though less certain, is of great importance! The natural fluctuations in the Earth's ambient temperature have been tracked for the past millennium from observations of the ratio of 0^{18} to 0^{16} in Greenland ice cores. According to W.S. Broecker in 1975 and P.R. Bell in 1989, the actual temperature of the Earth began to diverge from the natural fluctuations revealed by the Greenland ice cores in the past 40 to 50 years. The measured temperatures in this recent period have been higher than the expected natural fluctuations. This observation is consistent with a greenhouse warming but, of course, does not prove that the observed warming is a consequence of greenhouse.

A prudent custodian of man's future (to use an expression introduced by the energy analyst Palmer Putnam in 1953) surely would encourage the use of CO_2-conserving technologies. I would go further and argue that, given the uncertainties, simple prudence dictates that no CO_2-conserving technology be rejected. If a technology is deficient—perhaps because it is too expensive, or is perceived as being too dangerous—the technology should be fixed, not dismissed. Even if all plausible technologies are deployed, greenhouse warming may still engulf us; we cannot afford to ignore any possible CO_2-sparing energy strategies.

We know pretty well what energy technologies are CO_2-sparing. At the top of the list is conservation.

Next in importance is a shift from coal, which releases 0.025 GTC/quad, to oil (0.02 GTC/quad), to natural gas (0.015 GTC/quad). (Actually natural gas is not as benign as this comparison suggests, because unburnt methane is itself a much more potent greenhouse gas than is CO_2.) Of course, such a shift can be only a short-term expedient, at least if we are correct in our belief that the reserve of coal is far greater than is the reserve of either oil or gas.

Third, we ought to reforest since possibly as much as 1-2 GTC/yr is released from the destruction of the tropical forests.

Finally, we must get on with the nonfossil energy sources: biomass, fission, fusion, and solar.

II

A wish list such as this is easy to set down. Before it can be converted into policy, we must make assumptions about technology, about the future of man's energy demand, about the acceptability of a technology. Each of these is uncertain; perhaps the most uncertain is the future energy demand.

Man now uses about 300 quads (10 terrawatt-years per year or 300 quadrillion Btus/yr) of primary energy. Recent projections of energy demand 50 years from now (2040) by Fulkerson & Jones of the Oak Ridge National Laboratory range from about 450 quads/yr to about 750 quads/yr. The 450-quad scenario involves heavy conservation.

In no case does it seem possible to eliminate fossil fuel by the year 2040. The question then arises, is there an "allowable greenhouse budget" (AGB) of fossil fuel—i.e., an amount of carbon that, if injected into the atmosphere, would not lead to an increase in the CO_2 that resides in the atmosphere.

That there may be such a nonzero AGB is suggested in the observation that of the 6 GTC now injected per year, only about 3 GTC remains in the atmosphere—the "airborne fraction' is about 50%. The remaining CO_2 is absorbed either in the oceans or in the biosphere. L.D. Harvey, Maier-Reimer, and others have suggested that the AGB—i.e., the amount of carbon that could be injected *without* increasing the atmospheric burden of CO_2—is around 1.8 to 3 GTC/yr—i.e., 90 to 150 quad/yr of a 1/3:1/3:1/3 mixture of coal, oil, and gas.

I cannot stress how important it is for CO_2-energy policy to ascertain the AGB. Indeed, I should think that an important activity in a program of international cooperation on greenhouse would be a worldwide effort to determine the AGB. This is clearly a devilishly difficult problem, given that CO_2 distributes itself among many compartments in the oceans and the biosphere. But I don't believe anywhere near as much attention has gone into determining the AGB as has gone into estimating the temperature rise resulting from a doubling of CO_2. Yet from the point of view of energy policy, the AGB may be more important than the temperature rise.

III

In visualizing a desirable energy budget for year 2040, Fulkerson and Jones begin with an estimate of the AGB; they take this to lie between 90 and 150 quads/yr.

I give the remainder of their budget in Table 1 below.

TABLE 1.
A CO_2-Conserving Energy Scenario for the Year 2040

	High	Low
Total Annual Energy (quads)	750	450
AGB	90-150	90-150
Non-Fossil Budget (NFB)	660-600	360-300
Biomass	120-90	120-90
Solar & Other Renewables	60-30	60-30
Fission	0	0
Nuclear	420-540	120-240

Note that the amount of nuclear energy ranges from a low of 120 quads to a high of 540 quads. The 417 nuclear power plants in the world in 1987, with a total capacity of about 320 GWe, generated about 16 quads of heat and 1652 TWH of electricity (corresponding to an overall capacity factor of 59%). If we include the plants under construction and planned, the total number of plants reaches about 540, and the total output around 27 quads. Thus the Fulkerson-Jones scenario calls for an expansion of nuclear during

the next fifty years by a factor of 4 to 20—that is, a world nuclear system consisting of between 1200 and 7500 one-gigawatt reactors!

Is a nuclear system of this magnitude plausible? No one can say, since the acceptance of nuclear energy by the public hangs so much in the balance. I shall focus on only one aspect of acceptability: the probability of a reactor accident in a *very* large nuclear system. For definiteness, let me assume that, by 2040, we wish to deploy 5000 1-GWe reactors. Clearly, if the a priori median core-melt probability per reactor is $1/2 \times 10^4$ (as estimated by Rasmussen), this would imply a core-melt frequency, worldwide, of about 1/4/yr—that is, a core would melt an average of every 4 years. I regard this as unacceptable.

I cannot, nor can anyone, say what an acceptable core-melt frequency might be. As an alternative, I would favor developing reactors whose safety is transparent and passive, rather than being inscrutable and active. I come to this position from a belief that we live in "An Age of Anxiety," that probabilistic estimates of risk, Risk ($\sim$ Probability x Consequences) do not seem to satisfy an anxious public. If consequences are in principle sufficiently dire arguments that the probability of such a catastrophe is small carry little weight. Thus it seems to me that a necessary condition for deployment of *many* reactors over the next 50 years is the development of systems whose safety is perceived by the public, and particularly the skeptical elite, as being transparent and passive—in short, "inherent."

IV

The explicit search for inherent safety in technology probably began with the Flixborough cyclohexane explosion in 1973. Trevor Kletz, at the time in charge of safety at Imperial Chemicals, urged the redesign of chemical plants to incorporate principles of inherency and passivity in safety design.

Though safety had always been considered in the design of nuclear reactors, serious search for *inherent* safety really began at the time of Three Mile Island. Today, some 10 years later, passive safety has become a design criterion for most newly proposed reactors. There are *many* new proposals, all of which embody passive safety features. These range from relatively small incremental improvements on existing systems to more or less new concepts that deviate drastically from existing practice. In the first category I would put, say, the advanced light-water systems being proposed by several American vendors. In the latter category, I would place PIUS and its variants. In an intermediate category, I would place mod-HTGR and metallic-fuelled LMRs like PRISM.

V

Although I have emphasized the greenhouse effect as a rationale for developing a transparently passive reactor, I would not wish to leave the impression that this is the only incentive, or even the main incentive, for such development. The nuclear enterprise is all but moribund throughout most of the world. Even if greenhouse were not a reality, it seems to me prudent to inaugurate a second nuclear era in which nuclear energy has gained wide acceptance. A key to such a resurrection is a reactor that is transparently and passively safe.

Chernobyl seems to have brought the Soviet Union to some position not far from this one. At least, judging by the letter Secretary Gorbachev sent to the Director-General of the IAEA, the Soviet Union is interested in cooperating with the rest of the world in developing new and safer reactors. I have received informal confirmation of this view from some of my contacts in the Soviet Union.

I therefore strongly support the suggestion made by Jack Barkenbus to launch a point East-West project aimed at developing transparently-passively (t-p) safe reactors. There are two precedents for such development; the mod-HTGR now being planned by a Soviet team and the international CTR project inaugurated a few months ago.

I must say I am less clear as to *which* t-p reactor to recommend as the vehicle for such a collaborative venture. My strong inclination is to pursue ideas that represent drastic, not incremental, changes. This pretty much limits the choices. The three main contenders are mod-HTGR, PIUS, and metallic-LMR. Fortunately, mod-HTGR is being built, both in the Soviet Union and presumably in the United States—in the latter case, as a backup for the Savannah River replacements. This leaves PIUS and LMR. PIUS satisfies my criterion better than LMR. On the other hand, LMR can more easily be a breeder, which may be important in a *very* large nuclear energy system.

My suggestion is to pursue *both* LMR and PIUS. In making this suggestion, I am harking back to the early days of the first nuclear era, almost 50 years ago. Some 20 different systems were built, and 5 have been seriously deployed (PWR, BWR, RBMK, CANDU, LMFBR). Can we not resurrect the atmosphere and style of the beginning of the first nuclear era as we try to enter the second nuclear era? A two-pronged international effort to develop t-p reactors seems to me not unreasonable, given the importance of the goals of such a venture—a technical basis for defeating greenhouse and an acceptable nuclear energy!

WORKSHOP SUMMARIES
Workshop I—Environmental Challenges

INTRODUCTION

The degradation of the environment of Planet Earth is no longer a threat—it is now a reality that must be recognized. Such degradation is taking place on many scales, from loss of arable soil, to air and water pollution, to destruction of large areas of useful land by desertification, to global warming. Some of these effects could be reversed, but others appear to be irreversible on the time scale of human affairs. Furthermore, unless some remedial steps are taken immediately, this process of regional and global degradation can only continue to worsen, and environmental security for all people will be threatened.

The following conclusions and recommendations deal primarily with those remedial actions that must be taken. Countering the global environmental challenge will be a slow and extremely difficult process, and many of the steps to be taken are still not clear. Thus, we are directing these ideas to the sponsors of this conference and others who will be in a position to enlarge upon them. They will be of little value, of course, unless they lead to concrete actions in all parts of the world, so the dialogue must continue and be carried to the highest levels of government, industry, and academia.

At the root of the global crisis is obviously the growth of the human population. Mankind is making ever-increasing demands on the environment to feed and clothe and provide power to its people. This is especially critical in the Third World. Yet it is said (rightly or wrongly) that many people in the developing countries resent efforts by outsiders to assist in their family planning. In any case, our present national policy is to refuse aid to those countries that might wish to limit their burgeoning populations. How to deal with this complex problem is beyond the scope of our discussion—yet it is essential that the population explosion be addressed.

In a very real sense, our world is going through another transition. History tells us that first there was a transition from a hunting and gathering society to farming, then much later on a farming economy gave way to an industrial economy, and then there was a period when the nations of the world seemed to be obsessed with a struggle for military superiority and security. We are currently experiencing the longest period of peace between the major powers in the past several centuries. Now we are entering a period of environmental crises and a struggle for environmental security. Some of the unique features of this present transition are:

- It is an effort to provide security at both the national and the international levels, perceived now as a global imperative.
- While the other transitions were mostly spontaneous, now we must force and nurture the transition. Moreover, we must not expect it to take place rapidly, because there will be many serious obstacles, and at each stage there will remain uncertainties about its outcome.
- The process and its motivations will vary greatly from region to region, and will be quite different in the industrial countries than in the developing countries.
- The reality of the need for this transition is clearly perceived by scientists in all parts of the world, but almost everywhere political and economic priorities and pressures will have to be modified before it can take place. In general, the public does not share the sense of urgency felt by the scientific community, and it has to be educated before it will respond to the challenge.

CONCLUSIONS AND RECOMMENDATIONS

A Global Imperative: In the present situation, no one nation can claim that it has control over its environmental future. Some aspects of the environment may, of course, be modified by national action (e.g., water pollution, loss of soil, urban air pollution), but global changes such as greenhouse warming and depletion of stratospheric ozone can only be dealt with by international cooperation and action.

Role of Science and Scientists: Scientists have a special obligation to inform the public and its political and business leaders concerning the state of the environment, and also to reach some consensus, however inadequate, concerning future threats. At the same time, it will be difficult or impossible for scientists to address environmental issues without dealing with the even more pressing issues of poverty, famine, and disease, and the need for economic development both in Third World countries and in the industrial world. To meet these obligations scientists must:

- Focus on developing procedures and techniques to combine economic development with environmentally sound practices.
- Intensify environmental research and monitoring, both ground based and satellite based. This continuing effort must, of course, be international, and a free exchange of the latest information will be essential for its success.
- Seize every opportunity to inform the public about environmental concerns in a responsible way. In this role scientists must avoid conscious exaggerations and sensationalism, as this undermines their credibility. The media must clearly play a role in this process as an essential partner.
- Improve environmental education at every level, from elementary schools through colleges, so that environmentally sound practices may be applied more widely. In a broader sense, the purpose of such an education program must be to raise the level of public awareness of the reality of the global environmental crisis.
- Political scientists have an additional obligation to help translate scientific findings and recommendations into political action. This may include the creation of innovative institutional frameworks to infuse development programs with environmental concerns (but not to create a new international agency).

Facing the Problems of the Third World: Less developed countries have a particularly difficult problem in dealing with their own environments, and they will understandably not be greatly concerned with the global changes taking place. This is true because:

- They are often too poor to take the necessary action to correct their environmental problems.
- By the same token, their priorities put survival and obtaining enough food to feed their people ahead of longer term environmental concerns.
- The global insults to the Earth are largely the fault of the 25 percent of the world's population in the industrial countries that controls 75 percent of the wealth and energy. Thus, the Third World does not feel responsible for the global changes, nor indeed should it.
- The environmental degradation experienced by developing countries as they cut down their forests, extract other natural resources, and plunder their ecosystems is usually a result of demands by the rest of the world for their exports. Thus, the responsibility for their problems does not rest with them and their population pressures alone, but rather with the economic system which they share with the industrial world.

- The industrial world is not doing all it could to assist the Third World with better information, financial resources, and appropriate technology to deal with its population growth and environmental problems.

International Mechanisms and Agencies: There is probably no great need for a new international agency, either governmental or non-governmental, to promote this transition toward environmental security. There are a number of bodies already in existence whose mission is related to this goal in one way or another—ICSU, WMO, UNEP, FAO, UNESCO, IIASA, to mention a few. Instead, these bodies should be encouraged to cooperate with each other as a matter of urgency and to forget their past rivalries and disputes.

In this connection, it is noted that the United States has partially or totally withdrawn financial support to two potentially extremely useful bodies: The United Nations Environment Programme (UNEP), and the International Institute for Applied Systems Analysis (IIASA). The first was established after the U.N. Conference on the Environment in 1972 to encourage cooperation in environmental protection at the inter-governmental level; the second is a nongovernmental research institute sponsored by some seventeen national academies of science, including that of the U.S., whose goal is to bring together scientists from around the world to work on problems of common interest, particularly those resulting from scientific and technological development. These bodies deserve to be strengthened in every way possible, because they are prototypes of the kind of institutions that are most needed at this time.

Conversion to Non-Fossil Fuel Energy Technologies: Let us be realistic about the likelihood of the countries of the world relinquishing the use of fossil fuels in the near future. While we can and should promote non-CO_2-producing energy technologies and encourage energy conservation, we should expect the greenhouse gas concentration in the atmosphere to continue to rise for many decades, and, if this is so, then global warming is inevitable. It would be irresponsible to hold out a promise that this can be averted by international action now.

Slowing this climate change will require a worldwide effort to shift away from fossil fuels (and also to limit the destruction of tropical forests), starting immediately. However, that would require that we forego this most convenient source of energy, that we abandon the enormous worldwide infrastructure devoted to extracting and using coal, petroleum, and natural gas, and that we begin construction of alternative energy facilities. Are the industrialized countries ready to pay the costs? Will the less-developed countries be willing to defer their progress into the industrialized era while they wait for substitute energy sources? It seems unlikely that the answer to either of these questions will be affirmative.

However, in the long term we certainly can move away from fossil fuels, but only if we invest in research and development in solar energy technology, hydrogen as a fuel, inherently safe nuclear reactors for heat and electricity, and so forth. These, together with energy conservation methods, will buy us some time and slow the inevitable warming. The U.S. can and must play a lead role in all of the above efforts.

Assessing the Impacts of Climate Change: It is imperative that we look at the impacts of global warming by the greenhouse gases on a long term, because only then can we judge the costs of the damage relative to the costs of remedial action. There is a distinct likelihood that by the year 2050 the world will be 3 to 4°C warmer than now, and that there will be significant shifts of rainfall patterns. It should, in principle at least, be possible to estimate the costs of such a climate change in terms of farmland lost by more frequent droughts, forests dying as their favorable climate moves poleward, and lowlands invaded by rising sea level.

Before this assessment can be made properly we will have to have a better understanding of the climate system and a more detailed description of how it will respond. This can be achieved by a combination of

experiments with improved climate system models and studies of warm periods in the past. Furthermore, the social and economic disruptions caused by natural historical events such as prolonged droughts, subsidence of coastal areas, floods, and volcanic eruptions, can throw considerable light on how societies will respond and adapt to the environmental changes ahead. While the climate changes of the future will be unique in some respects—notably their magnitude and rapidity—we can surely learn much from past experiences.

This assessment of the impacts of climate change will help to place the change into a human framework. Without such a framework long-range policy decisions are extremely difficult. At what point will the leaders of the world decide that the climate change is becoming "unacceptable"? When will sacrifices of short-term economic benefits have to be made in favor of the welfare of future generations? We can expect such agonizing questions to be asked with increasing insistence in the years ahead.

Workshop II—Fission Energy

Nuclear Energy, 50 years after the discovery of fission, now produces 17% of the world's electricity. Yet in a real sense, the era of nuclear energy seems to be ending. In view of the possibility that the nuclear option can contribute to the resolution of severe global environmental dilemmas, we believe that the world ought to recommit itself to serious investigation of an acceptable nuclear option. Such a recommitment will require a re-examination of almost every aspect of the nuclear enterprise.

1. *Nuclear Reactor Safety*: We believe attention must be paid both to the safety and good operation of the existing fleet of some 500 power reactors, and to the development of a new generation of reactors possessing additional elements of transparent and passive safety. We have identified international cooperative ventures aimed at both these goals, for example:
   - Exchange of information on improved management systems for rationalizing operations of existing reactors (we therefore recommend extension of such multinational activities as the world association of nuclear operators, various international owner groups, and interlinked data systems).
   - Possible formation of other consortia to build a small, passively safe reactor that particularly fits the needs of countries requiring small reactors.
2. *Waste Disposal*: Every country that uses nuclear energy is engaged in research on nuclear wastes. Yet in many countries, the public remains skeptical. We recommend that certain multilateral actions, in addition to those already underway, may be helpful, via
   - international cooperation in development of a thermodynamically stable waste package such as the Australian Synroc or the Swedish Copper Canister,
   - exchange of personnel at the various geologic test laboratories now in existence such as the Canadian Laboratory near Whiteshell, Manitoba,
   - reconsideration, on an international basis, of the possible use of the sea bed for radioactive waste disposal.
3. *Safeguards*: The connection between nuclear power and nuclear bombs remains troublesome, and continued, improved effort, largely through the IAEA, to break this connection is indicated. We therefore recommend:
   - Continued support, on a multinational basis, for efforts to strengthen the technical basis for the IAEA's nonproliferation regime and for various world-wide efforts to forestall nuclear terrorism.
   - Spent fuel storage at international centers under IAEA monitoring—a possibility that remains attractive, despite a history of rejection.

4. *Low-Level Radiation Hazard*: Much of the public's disaffection with nuclear energy arises from fears of the deleterious effects of low levels of radiation. We therefore recommend:
   - Continued collaboration among countries in establishing the dose-response curve at low doses. A good example of such collaboration is the joint Japan-U.S. collaboration, now almost 45 years old, for assessing the medical consequences of the atomic bombs. Similar collaboration between the USSR and other countries on the Chernobyl accident are indicated. Despite our best efforts, it is unlikely that the dose-response at the lowest levels can be ascertained. We therefore recommend that the International Committee on Radiation Protection address, in full seriousness, the establishment of a de minimis dose—say 10^{-4} S/y (10 mR/y), which is small compared to the natural background.
5. *Economics*: Nuclear power will not be available to help solve environmental issues unless it is economically competitive. Though we have no specific recommendations to make for international measures that can enhance the economic viability of nuclear power, we recognize that the economics of every energy source, including nuclear power, depend upon the economics of its competitors. We therefore urge that the world accelerate its investigation of the major long-term alternatives to nuclear fission (fusion, solar, and conservation) with the interim possibility of cleaner fossil fuel, so that intelligent choices as to realistic, economical energy alternatives can be made.

We therefore note:

The international ITER Project for designing a fusion self-igniting reactor is now underway, but there is no commitment to build such a device if the design effort is successful. We urge that such a commitment be made.

We believe that solar energy, which has fallen into some disrepair in most of the world, ought to be revitalized with some of the research conducted cooperatively.

6. *Nuclear Energy and the Public*: Nuclear energy has foundered as much as anything because the public in many countries has lost confidence in nuclear technology and in the nuclear establishment. Regaining the public's confidence will not be easy. We hope the technical measures that we have suggested will help. Safe operation is also essential to forestall recriminations between countries as was evident following the Chernobyl accident. Beyond this, we urge that once the technology, wherever developed, reaches the norms of safety aimed at in this statement, these developments *must be properly communicated* to the public. Such communication must be continuous, persistent, and understandable. It must place nuclear risks in the context of other risks attendant on energy production.

We have in this statement outlined actions that serve two purposes:

1. The re-establishment of an acceptable nuclear energy that will be available in the twenty-first century, should it be needed.
2. A collection of collaborative efforts which, if carried out, will further this purpose and would also, by virtue of their international character, help in building confidence among nations and peoples.

Finally, we note that the measures we propose are not inexpensive. We would only suggest that in the current atmosphere of international comity, the world's armament budget of \$900 x 10^9/y ought to fall substantially. We would hope that at least some of the money thus saved might go into a worldwide commitment to re-establishing a nuclear-energy option that, in every respect, is acceptable to humankind.

Workshop III—Conservation, Fossil Fuels, and Renewables

1. An International Center for Research on Energy and the Environment should be established. Its scope should include the basic sciences, technology development, and policy formulation. It should speak with authority about quantitative matters by virtue of its direct involvement in measurement and modeling and should maintain data bases. It should also develop special capabilities related to technology transfer to the less-developed countries (LDCs).

   Issues worthy of further discussion:

   - A single Center or several?
   - U.S.-Soviet or multi-national governance?
   - Exclusive focus on global problems, or also local problems?
   - Exclusive focus on long-term, or also immediate issues?
   - Coordination with related institutions (UNEP, IIASA)?

2. Because global limits to carbon emissions may become the subject of new international agreements, collaborative projects should be established to provide the technical basis and the policy mechanisms for such agreements.

3. An Environmental Action Corps should be launched, as a new policy initiative of the United States. Personnel for this Corps could be provided in part via a federal college-level training program. Other countries should be encouraged to develop parallel programs.

4. In choosing bilateral projects, special weight should be given to those that facilitate the transfer of relevant defense technologies to environmental and energy problems.

5. Collaborative projects should be developed addressing end-use efficiency for all sectors of the economy (transportation, buildings, industry). Projects should also be developed addressing efficient energy conversion, transmission, and distribution. Interactions between supply and end-use should be explored. In all projects, emphasis should be given to minimizing adverse environmental impacts.

6. Because resource extraction at today's scales and with today's technologies severely challenges environmental objectives, bilateral projects that focus on this dimension of the energy-environment agenda should be formulated.

7. Existing experimental facilities and field sites in the Soviet Union and the United States should be exploited in research projects to achieve the full promise of these investments and to reduce overall costs.

8. Because future energy use in the LDCs looms so large from the standpoint of global environmental problems, a research program is needed that gives prominence to advanced technologies that enhance energy efficiency and economic development. Examples are biomass-based industrial processes, energy-efficient basic-materials production, and cooking technologies.

9. Creative dissemination of the results of this conference should be pursued. There should be a role for the U.S. National Academy of Sciences and for the Academy of Sciences of the U.S.S.R. Special efforts should be made to inform the legislative and executive branches of all countries.

10. A Bush-Gorbachev "Environmental Summit" should be convened. This Summit could be held at a LDC site, such as UNEP headquarters in Nairobi, Kenya. One accomplishment of this Summit could

be the announcement of the International Center for Research on Energy and the Environment (see recommendation 1), together with its first projects.

Workshop IV—Disaster Response

Goal of disaster response:

Minimize death, injury, environmental insult, and other negative consequences of both natural and man-made disasters and expedite recovery.

Proposed initiatives:

- Improve the predictive capability for natural disasters such as earthquakes, hurricanes, tornados, floods, and tsunamis.
- Improve the predictive capability for the consequences of radiological accidents, chemical accidents, and other man-made disasters.
- Improve the capability for modeling disasters such as disease and war.
- Establish an international center (probably within UN as per Soviet proposal) to coordinate disaster response programs.
- Establish programs on prevention and mitigation of both man-made and natural disasters.

International Disaster Response Center

Background

Rareness of major events makes it difficult to maintain preparedness:

- difficult to maintain budgets
- difficult to find data or learn from past events
- difficult to establish and maintain plans.
- difficult to maintain motivation.

To assure preparedness, external enforcement is necessary from:

- government agencies
- treaties or formal agreements
- regulations or laws.

For adequate response, managers and equipment must be in place within minutes of the accident. This requires advance preparation.

Features of the program. It will:

- Provide guidance in preparing Emergency Response (ER) plans
- Review existing ER Plans
- Conduct drills
- Maintain a database of experts and equipment

- Dispatch experts and equipment upon request from a member state
- Provide incentive and information for honest news reporting
- Provide rapid plume modeling at site
- Request needed research
- Conduct annual symposium on improving capabilities. Representatives of member governments, industry, public, technical experts, and international agencies would attend.

Membership

- Operators—Industries, Government, Trade associations
- Regulators—Government Agencies, International Agencies
- Insurers
- Public

Participants

- IAEA and Other International Agencies
- ARAC, National Response Center
- Government Agencies
- Industry Associations
- Red Cross/Red Crescent
- UNIDRO, UNEP and other UN Agencies
- National Response Teams
- Chemtree
- Other National Experts

AIR QUALITY STUDIES IN THE WESTERN UNITED STATES

by

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INTRODUCTION

There are several on-going air quality studies in the western United States: SCENES,[1] DMAT,[2] GLADIS,[3] and SCAQS.[4] These projects have their own objectives and focused on specific areas of interest. There are, however, some objectives common to all the projects. They are:

1. To quantify the source/receptor relationship, i.e., to estimate how much each source contributes to the pollutants distribution, and
2. To develop a data base for testing, evaluating, and improving air quality simulation models.

Los Alamos investigators participated in SCENES, WHITEX, Winter Intensive Tracer Experiments conducted from January 7 through February 18, 1987, in the area 400 km (east-west) x 250 km (north-south) centered around Page, Arizona. The purpose of the experiment was to quantify the contributions of a local source (Navajo Generating Station) and remote sources (copper smelters in southern Arizona, Mojave generating station, power plants and large urban areas) to the haze occurrences in the Grand Canyon National Park, Canyonlands National Park, and Glen Canyon National Recreation area.

In order to "tag" plumes emitted from the Navajo Generating Station (NGS), a trace gas was released from the NGS stack during the entire experimental period. Some of the highlights from the measurement program are:

1. Consistently higher sulfate concentrations at Canyonlands National Park (northeast of NGS) than at Grand Canyon National Park (southwest of NGS),
2. Consistently lower trace gas concentration at the Canyonlands than at the Grand Canyon National Parks,
3. Consistently higher concentrations of sulfate and trace gas at Page than at Hopi Point (Grand Canyon),
4. Little systematic diurnal variation in the observed trace gas concentration, particularly in the Grand Canyon area,
5. Little correlation between the upper-air wind direction and the surface concentrations of trace gas and sulfate, and
6. Large variation in the wind direction with height.

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[1] Subregional Cooperative Electric Utility, Department of Defense, National Park Service and Environmental Protection Agency Study
[2] Desert and Intermountain Air Transport
[3] Greater Los Angeles Distant Impact Study
[4] Southern California Air Quality Study

Items 1 and 2 apparently contradict each other unless there were additional SO_2 sources in the vicinity of the Canyonlands National Park while tracer was released only from NGS. On the other hand, both trace gas and sulfate behaved similarly, as evidenced in Item 3. Item 5 is very unlikely for plumes transported over flat terrain, but is quite possible over complex terrain since wind direction varies considerably with height due to wind circulations generated by differential heating and cooling of the sloped surfaces.

The purpose of this paper is to illustrate, by using Los Alamos three-dimensional atmospheric flow models, large diurnal and spatial variations of wind, turbulence, and plume characteristics over complex topographic areas.

MODEL DESCRIPTION

The basic equations for mean wind, temperature, mixing ratio of water vapor, and turbulence are similar to those used by Yamada, et al., elsewhere in this proceedings. Transport and diffusion is modeled by using a Lagrangian statistical random-particle method, and the concentration of trace gas is computed by assuming a Gaussian concentration distribution centered at a particle location. Standard deviations of the Gaussian distribution were computed from Taylor's (1921) theorem and the modeled standard deviations of velocity components. Both meteorological and diffusion models used in this study are fully described by Yamada and Bunker (1988), and are not repeated here, with the exception of a brief description of initial and boundary conditions.

Surface boundary conditions are constructed from empirical formulas by Dyer and Hicks (1970) for nondimensional wind and temperature profiles. The temperatures in the soil layer are obtained by solving the heat-conduction equation. Appropriate boundary conditions are the heat energy balance at the soil surface and specification of the soil temperature at a certain depth.

The turbulent fluxes (momentum, heat, and water vapor) are obtained from simplified turbulence-closure equations (Yamada, 1983). The long-wave radiation flux is computed according to Sasamori (1968). The lateral boundary values are obtained by integrating the corresponding governing equations except that variations in the horizontal directions are all neglected.

The computational domain is approximately 120 km (east-west direction) x 150 km (north-south direction) centered at around Page, Arizona. The top of computational domain is placed 3500 m above the highest ground elevation (3080 m above mean sea level) in the study area. An initial wind profile at the southwestern corner of the computational domain is first constructed by assuming a logarithmic variation (initially $u_* = 0.2$ m/s and $z_o = 0.1$ m) from the ground up to the level where the wind speed reaches an ambient value (3 m/s). Initial wind profiles at other grid locations are obtained by scaling the southwestern corner winds to satisfy mass continuity. Wind directions in the upper layers are assumed to be southeasterly everywhere. The vertical gradients of the synoptic potential temperature are assumed to be 0.0005 K/m for the height equal or lower than 1900 m msl, and 0.008 K/m for the levels higher than 1900 m msl.

Initial potential temperatures are assumed to be uniform in the horizontal directions. The turbulence, kinetic energy, and length scales are initialized by using the initial wind and temperature profiles, and the relationships obtained from the level 2 model. These expressions are given by Yamada (1975).

The governing equations are integrated by using the Alternating Direction Implicit method (Richtmyer and Morton 1967) and a time increment is chosen to satisfy the Courant-Friedrich-Lewy criteria. In order to increase the accuracy of finite-difference approximations, mean and turbulence variables are defined at grids that are staggered both in horizontal and vertical directions. Mean winds, temperature, and water vapor

vary greatly with height near the surface. In order to resolve these variations, nonuniform grid spacings are used in the vertical direction.

RESULTS

The purpose of the present study is to understand the mechanisms that resulted in large variations in space and time of wind and turbulence distributions in the WHITEX study area. This is essential in resolving the seemingly contradicting behavior of the sulfate and trace-gas concentration distributions discussed earlier.

Figure 1 shows a three-dimensional representation of the ground elevation of the simulation area. The horizontal grid spacing of 4 km is used for both in the x (east-west) and y (north-south) directions. The vertical grid spacing is small (4 m) near the surface to resolve the large diurnal variations of wind and temperature profiles, and gradually increases with height. A total of 30 x 38 x 24 (vertical) grid points are used to cover the area of 116 km x 148 km x 6.6 km (vertical). The computation initiated at 5 pm on Julian day 32 and continued for 57 hours to obtain wind and turbulence distributions for trace-gas concentration simulations.

Figure 2 illustrates typical nighttime (Fig. 2a) and daytime (Fig. 2b) modeled wind distributions near the surface (14 m above the ground). During the nocturnal period (Fig. 2a), the surface wind directions are downslope since the air near the surface cools faster and becomes heavier due to the longwave radiation cooling than the air at the same level but away from the sloped surface. Exactly the opposite happens during the convective daytime and the surface wind direction becomes upslope (Fig. 2b). The sloped surface faced east and south receives the sun's heating earlier than the surfaces facing west and north. The differential heating and large-scale pressure gradient imposed in the simulations resulted in heterogeneous and asymmetric distributions of wind vectors (Fig. 2b).

In addition to winds, turbulence also exhibits large diurnal variations. The long-wave cooling at the ground surface produces stable air-density stratification and suppresses turbulence motion. Figure 3a shows the standard deviation of the vertical wind component. On the other hand, turbulence motion is greatly enhanced during the daytime due to strong heating from the sun at the ground. The corresponding standard deviation of the vertical wind component at 2 p.m. (Fig. 3b) is much larger in magnitude and deeper in the vertical extent than the counterpart at 1 a.m. (Fig. 3a).

The modeled wind and turbulence distributions are used to compute transport and diffusion of a trace-gas from NGS. The trace-gas plume is represented by many puffs released continuously at NGS. The effective height of the plume at NGS was estimated to be 500 m above the ground. Projections of the modeled puff centers at 2 pm and 7 pm are shown in Fig. 4a and Fig. 4b, respectively. The modeled turbulence apparently reached the plume height (500 m above the ground) around 2 pm (Fig. 4a) evidenced by the disturbed distribution of the puff centers. The modeled puff centers continued to spread horizontally as well as vertically due to the combination of the intensified turbulence and wind shears in the vertical direction (Fig. 4b). The modeled concentration of trace gas (Figs. 5a and 5b) at the ground level also shows considerable variations in space and time. The concentration contours represent the values after $\log_{10}$ is applied. For example, -5 contour represents the concentration of 10^{-5} g/m^3. The daytime concentration distribution (Fig. 5a) retains a plume-like feature but the nighttime counterpart (Fig. 5b) shows very complex and nonhomogeneous characteristics that cannot be simulated by a simple Gaussian model.

Finally, the modeled surface concentrations at Page averaged over 6 hours are plotted as a function of the local time in Fig. 6. The dotted line indicates the averaged concentration over the entire simulation period. The modeled daytime peak concentration and averaged concentration over the entire simulation period are in good agreement with the observations but the nighttime values are slightly underestimated.

ACKNOWLEDGEMENT

This work was supported by the U S Department of Energy.

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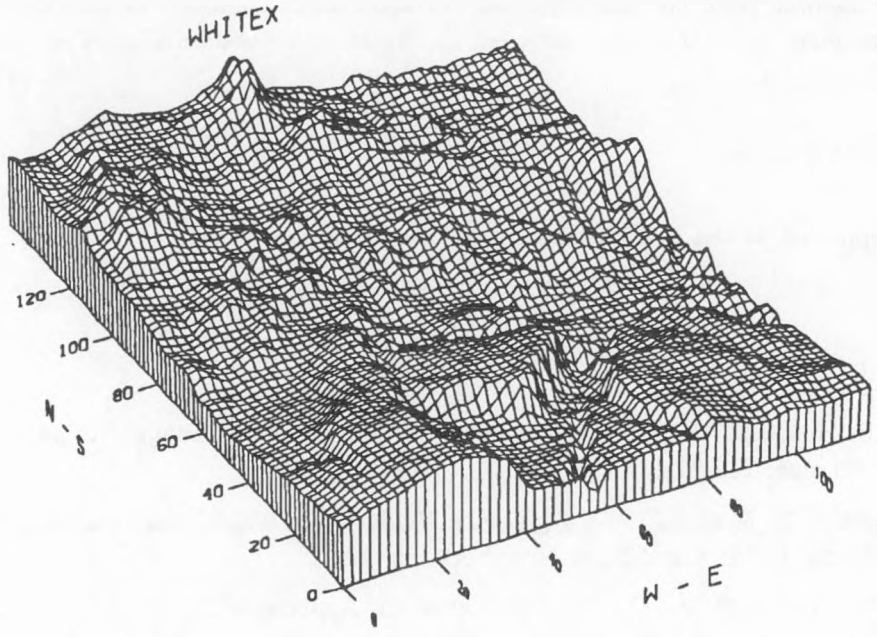


Figure 1. Three-dimensional representation of the topography for the area simulated.

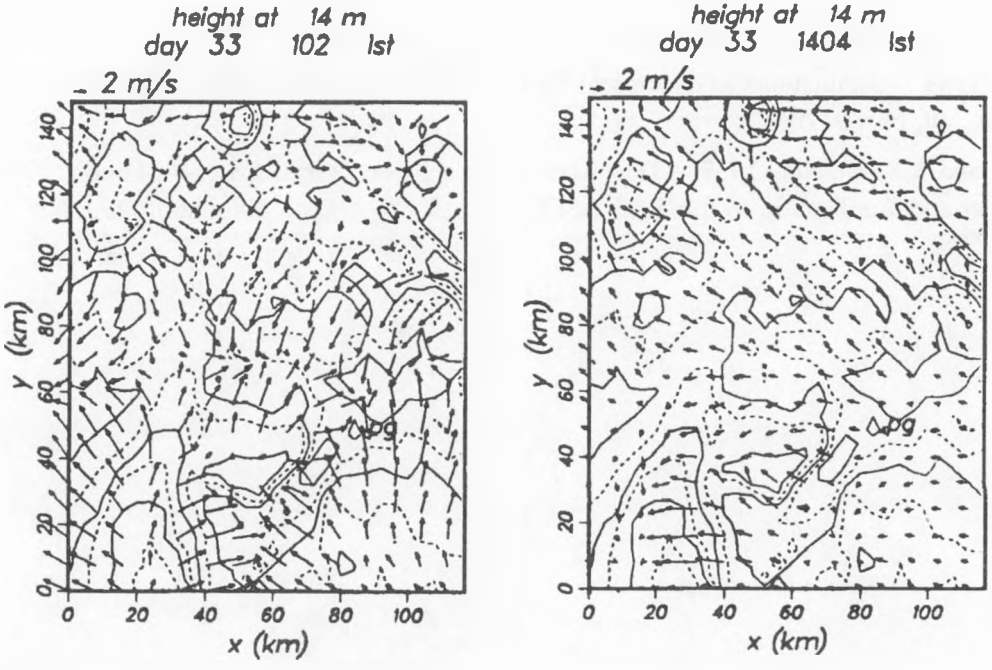


Figure 2. Modeled wind vectors at 14 m above the ground. Terrain is contoured by solid lines with an increment of 400 m with dashed lines at intermediate levels. a) at 1:00 am and b) at 2:00 pm.

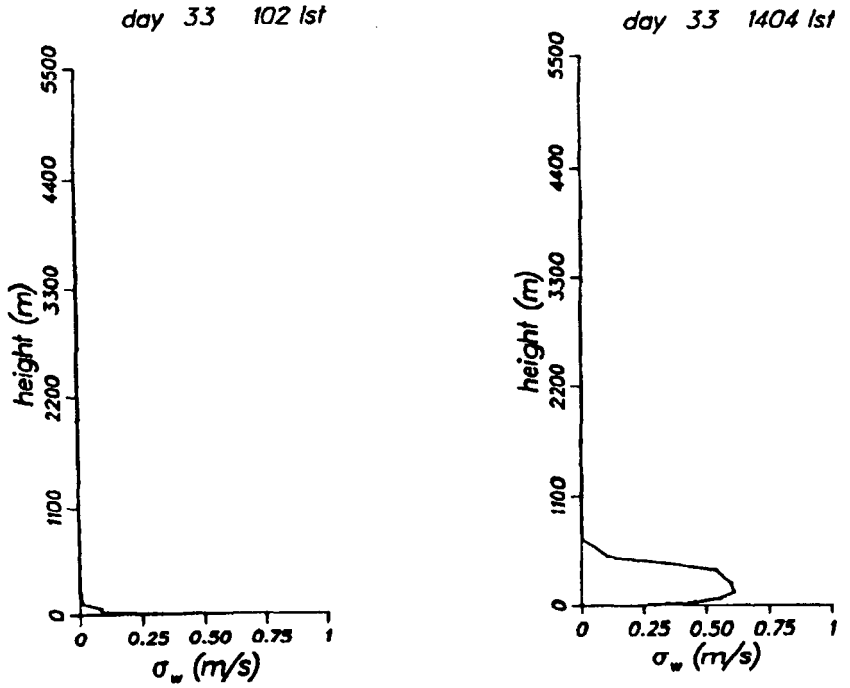


Figure 3. Vertical profiles of the modeled standard deviation of vertical velocity at a) 1:00 am and b) 2:00 pm.

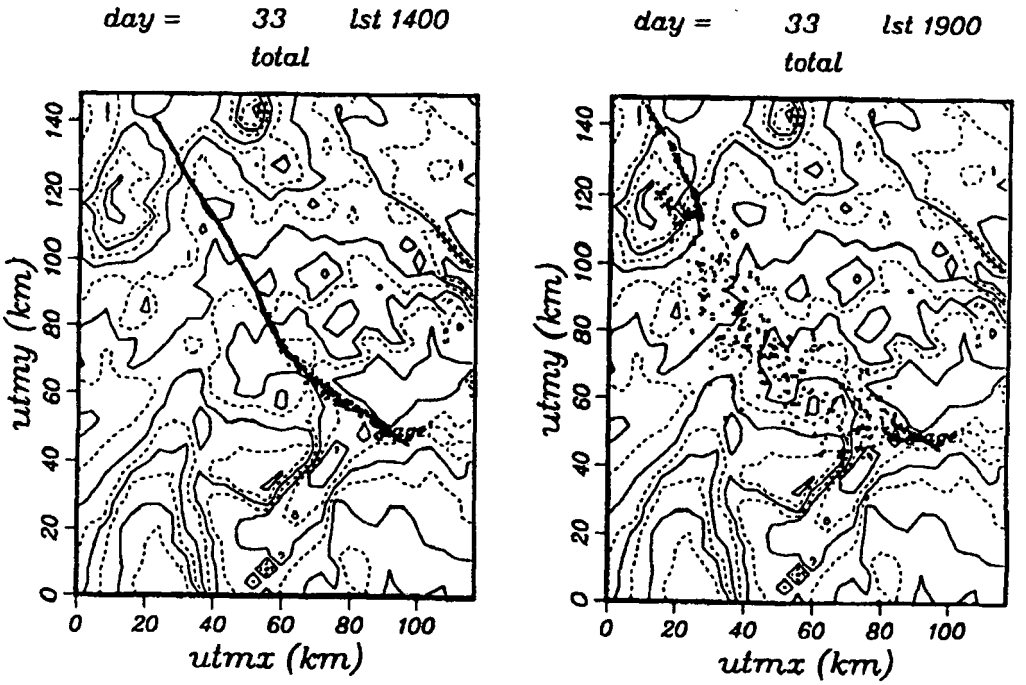


Figure 4. Trajectory of the modeled puff centers projected on the surface at a) 2:00 pm and b) 7:00 pm.

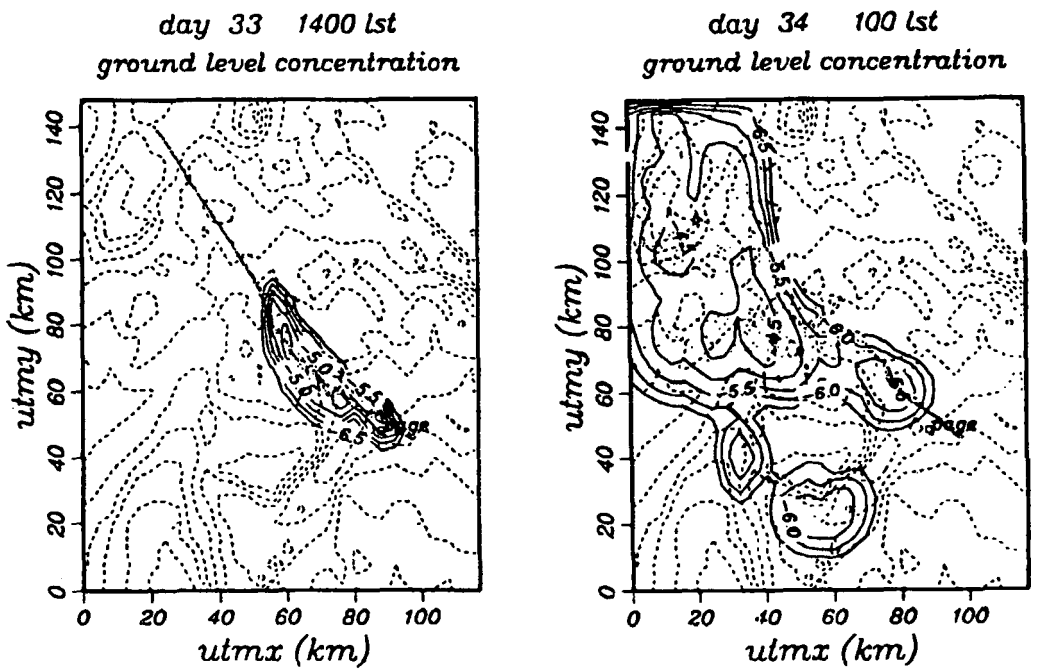


Figure 5. Modeled concentration of a trace-gas at the surface. Concentration (gm^{-3}) is given in terms of $\log_{10}$.

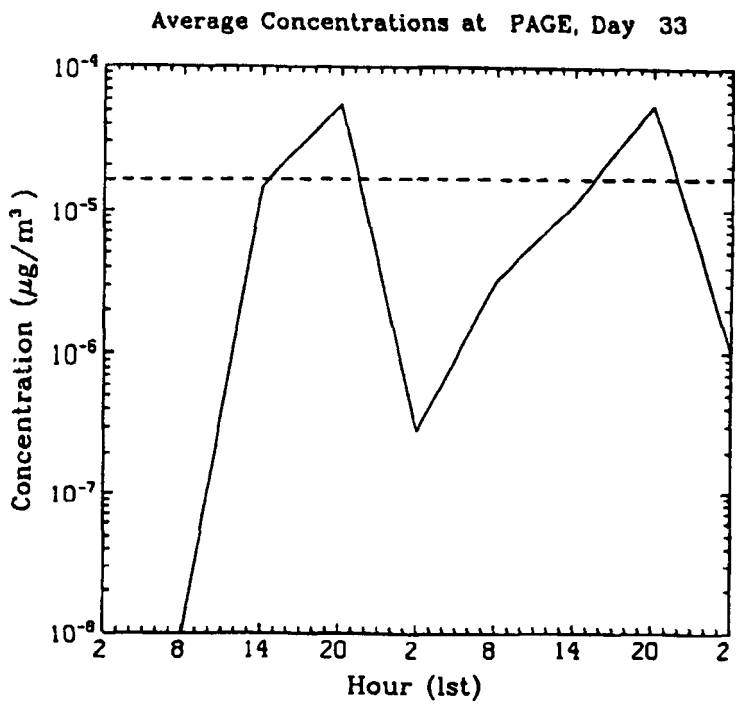


Figure 6. Time variations of the modeled trace gas concentration averaged over 6 hours at Page, Arizona. The dashed lines indicates an average value over the entire simulation period.

A DESK-TOP COMPUTER FORECAST FOR EMERGENCY RESPONSE PLANNING

by

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INTRODUCTION

The purpose of the study is to demonstrate the feasibility of running a three-dimensional weather forecast model on a desk-top computer. For emergency response planning, the ability to forecast wind, temperature, and atmospheric turbulence is essential in order to predict the transport and diffusion of an accidental release of toxic materials. We must follow a plume for a long distance to meet tighter regulations to protect human health and the environment.

Most models for emergency response are based on the assumption that wind and turbulence conditions at the time of the release will be representative over the period for which dispersion must be predicted. For small releases where the principal concern is within the first few kilometers of travel, such an assumption is appropriate. However, for large releases during stable conditions, the plume may travel for several hours and the assumption of persistence is invalid. Under these circumstances a model which can forecast changes in wind and turbulence conditions is required.

Persistence is a particularly poor assumption to make in mountain valleys and coastal locations. In the coastal locations, we have land-sea breeze phenomena, whereas the mountain valleys we have the mountain valley wind system. In both instances abrupt changes in wind direction can be expected during the diurnal cycle, and the wind direction at a given time is very sensitive to the location where the winds are measured.

A diagnostic model needs a large number of measurements in time and space to represent accurately the airflows in complex terrain. Such extensive measurements could become very expensive and are not practical. Diagnostic models, by themselves, do not provide an adequate solution to emergency response management since they have little predictive capability. A forecast model, on the other hand, can forecast locally generated diurnal circulations driven by terrain features. With recent advancements in small computer capabilities, it is possible to run a three-dimensional forecast model for practical applications.

MODEL DESCRIPTION

The basic equations for mean wind, temperature, mixing ratio of water vapor and turbulence are similar to those used by Yamada and Bunker (1988). Surface boundary conditions are constructed from the empirical formulas by Dyer and Hicks (1970) for nondimensional wind and temperature profiles. The temperatures in the soil layer are obtained by solving the heat conduction equation. Appropriate boundary conditions are the heat energy balance at the soil surface and specification of soil temperature at a certain depth.

The turbulent fluxes (momentum, heat, and water vapor) are obtained from simplified turbulence-closure equations (Yamada, 1983). The long-wave radiation flux is computed according to Sasamori (1968).

The lateral boundary values are obtained by integrating the corresponding governing equations except that variations in the horizontal directions are all neglected. The model is applied to simulate airflows over the area 80 km x 80 km centered at Los Alamos, New Mexico.

An initial wind profile at the southwestern corner of the computational domain is first constructed by assuming a logarithmic variation (initially $u_* = 0.2$ m/s and $z_o = 0.1$ m) from the ground up to the level where the wind speed reaches an ambient value (2 m/s). Initial wind profiles at other grid locations are obtained by scaling the southwestern corner winds to satisfy mass continuity. Wind directions in the upper layers are assumed to be northwesterly everywhere. The vertical gradients of the synoptic potential temperatures are assumed to be 0.01 K/m for the height equal or lower than 3500 m above mean sea level (msl) and 0.005 K/m for the levels higher than 3500 m msl.

Initial potential temperatures are assumed to be uniform in the horizontal directions. The turbulence kinetic energy and length scale are initialized by using the relationships obtained from the level 2 model. These expressions are given by Yamada (1975).

The governing equations are integrated by using the Alternating Direction Implicit method (Richtmyer and Morton, 1967) and a time increment is chosen to satisfy the Courant-Friedrich-Lewy criteria. In order to increase the accuracy of finite-difference approximations, mean and turbulence variables are defined at grids which are staggered both in horizontal and vertical directions. Mean winds, temperature, and water vapor vary greatly with height near the surface. In order to resolve these variations, nonuniform grid spacings are used in the vertical direction.

RESULTS

The purpose of the study is to demonstrate the feasibility of running a three-dimensional atmospheric code to assist emergency response management. However, the results presented here are still preliminary and have not yet been verified with data.

Figure 1 shows a three-dimensional representation of the ground elevation in the studied area (80 km x 80 km). The horizontal grid spacing of 4 km is used for both x (east-west) and y (north-south) directions. The vertical grid spacing is small (4 m) near the surface to resolve the strong diurnal variations of wind and temperature profiles, and gradually increases with height. A total of 21 x 21 x 16 (vertical) grid points are used to cover the area of 80 km x 80 km x 6 km (vertical). The computation initiated at 0400 LST (Local Standard Time) on Julian day 187 (July 6) and continued for 24 hours to examine the diurnal variations of wind and temperature. All computations and graphics are performed on a SUN Microsystem Model 4/110 workstation.

By 0800 LST, well organized convective upslope flows develop in the layer close to the surface (Fig. 2). A grid point is located at the tail of each wind vector, indicated by an arrow. The length of an arrow is proportional to the wind speed. A wind scale is given at the right lower side of the figure. The upslope flows remain throughout the daytime and the depth of upslope flows increased with height (e.g., 500 m above the ground at 1500 LST at the Los Alamos site).

Wind directions and speeds began to change responding to the decreases in the surface temperature which peaked at around 1400 LST. As the air temperature near the surface become lower than the air

temperature away from the sloped surface, nocturnal drainage flows develop (Fig. 3). Wind directions in Fig. 3 are almost reversed from those in Fig. 2 indicating strong influence of the terrain features. Throughout the simulations, the wind direction in the upper levels remained northwesterly, the initial wind direction.

The modeled atmospheric turbulence also shows strong diurnal variations in intensity and vertical extent. The daytime values are significantly higher than the nocturnal counterparts. Large temporal and spatial variations in the wind and turbulence distributions are clearly important factors to be taken into consideration for predicting transport and diffusion of airborne materials in complex terrain.

SUMMARY

A three-dimensional weather forecast model is run on a desk-top computer for applications in emergency response modeling system development. There are still many improvements and developments needed before the present system becomes operational. We are currently working on the linkage to the wind and temperature distributions forecasted by the National Meteorological Center which will provide the large scale weather variations to the present model.

ACKNOWLEDGEMENT

This work was supported by the US Department of Energy.

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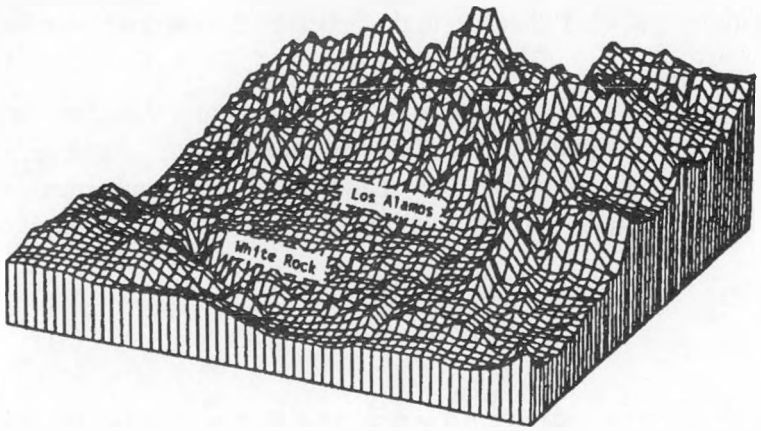


Figure 1. Three-dimensional representation of the topography for the area simulated.

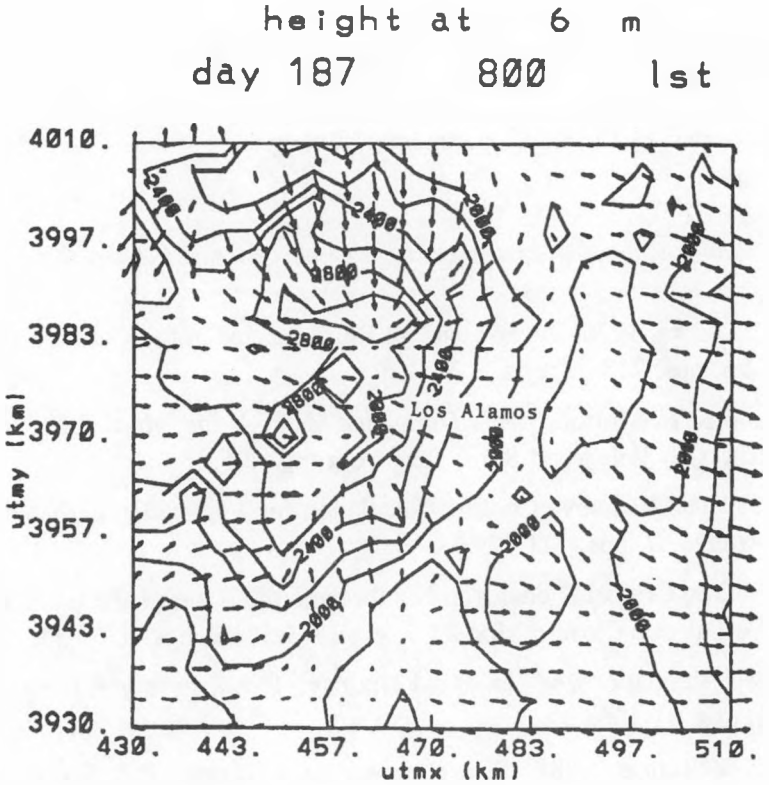


Figure 2. Modeled wind vectors at 6 m above the ground at 0800 LST. Terrain is contoured by solid lines with an increment of 200 m.

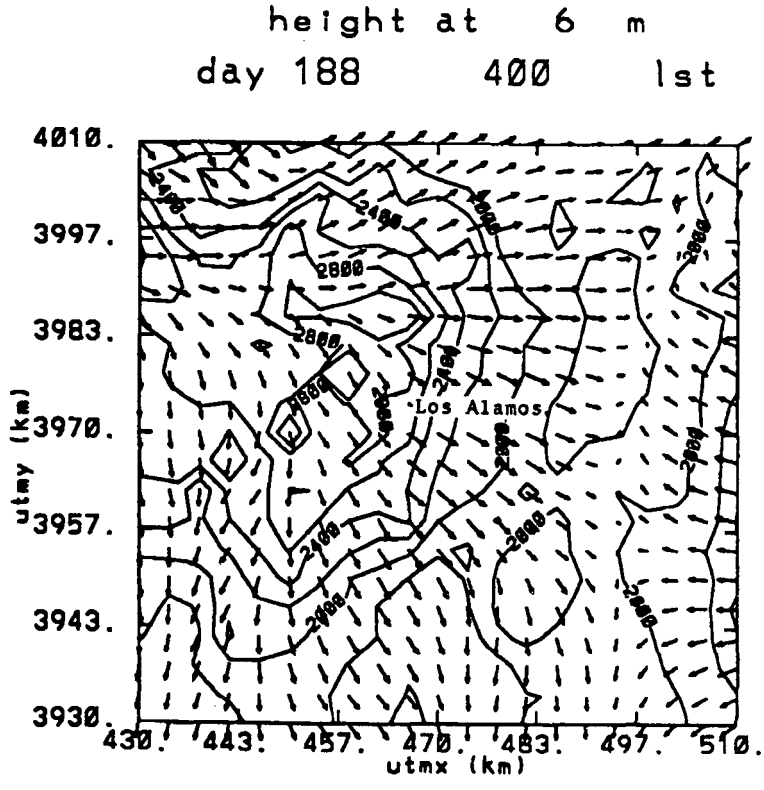


Figure 3. Modeled wind vectors at 6 m above the ground at 0400 LST. Terrain is contoured by solid lines with an increment of 200 m.

NUCLEAR ENERGY, COAL, AND ENVIRONMENT

by

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ABSTRACT

From the view point of environmental protection, nuclear plants are superior to coal-fired ones. Coal-fired plants and other uses of burning create serious environmental problems, whereas no noticeable impacts are identified for nuclear plants. Even with respect to radiation risk, with equal energy output, a coal-fired plant is one order of magnitude higher than a nuclear station.

Energy is a prerequisite for the development of a national economy and the improvement of living standards. Economic growth must be coordinated with the exploitation of energy resources. The worsening shortage of energy has made it imperative that China step up its energy development and pay full attention to the development of nuclear energy. Among direct energy sources, about 70% came from coal in the past. The public has been greatly concerned over the pollution caused by coal-fired power stations and/or other industrial and domestic use of coal burning. With increasing mining of coal, the issues related to pollution from the use of coal will become more serious and prominent.

IMPACT OF RADIOACTIVE WASTE

It is natural for people to assume that nuclear power stations would release much larger amounts of radioactive materials to the environment than do coal-fired ones, as their name implies. However, the facts are contrary to people's intuition. Table 1 lists the normalized collective doses to the surrounding public near nuclear and coal-fired power stations.[1-4] As seen from the table, the normalized collective doses for the former are lower or much lower than for the latter. The different dose values from different coal-fired power stations are due mainly to different stack dust-collector efficiencies. As a whole, the efficiency of dust-collectors for coal-fired plants is around 90% in China, so the corresponding normalized collective dose was estimated to be 50 man $\cdot$ Sv $\cdot$ GWe^{-1} $\cdot$ a^{-1}, which is one order of magnitude higher than the world average value of 4 man $\cdot$ Sv $\cdot$ GWe^{-1} $\cdot$ a^{-1} recommended by the UNSCEAR Report of 1988.[5] The reason for this, in addition to the higher population density and the lower efficiency of stack-dust collectors in China, is the higher content of natural radioactive materials in coal. Table 2 lists the concentration of natural radionuclides in coal of Chinese origin and the normal world value adopted by UNSCEAR.[1-5] In the table, the data reported by reference 6 are based on the whole country, except for the Guandong and Tibet autonomous regions, and so are considered to be representative of the country. The data summed by reference 7 come from 61 major coal-fired power stations, and so are similarly representative. The two sets of data are apparently close to each other and roughly 2 times as large as that given by UNSCEAR.[5]

Table 1. Normalized collective doses to public near coal-fired and nuclear power stations.

	A	B	C	ref.
coal-fired	43	100		1
coal-fired	68	80	90	2
coal-fired	2.38		98~99	3
nuclear	1.6	80		4

Note: A, the normalized collective dose man · Sv · GWe^{-1} · a^{-1};

B, radius of collective dose assessment, km, with the origin at the power station;

C, percentage collecting efficiency of stack dust-collector.

Table 2. Concentration of radionuclides in coal

		concentration, Bq · kg^{-1}				
	number of samples	^{238}U	^{226}Ra	^{232}Th	^{40}K	ref.
24 provinces, China	563	55	34	30	104	6
61 coal-fired power stations, China		46		42.5	127	7
Yining, Xinjiang, China						
-high bituminous coal	98	42.4	52.5			8
-bituminous coal	9	32.1	39.2			
Zhejiang, China						
-stone-coal		250-3000				9
UNSCEAR		20		20	50	5

It should be noted that the normalized collective doses from coal-fired power stations mentioned above only account for thecontribution of airborne effluent from stacks. As we discussed before in another paper, including the contribution of coal cinder or ash would result in radiation doses that cannot be ignored. It was estimated that if 5% of the coal cinder of the country were used for housing construction, the additional collective dose would be around 7.2 man · Sv · GWe^{-1} · a^{-1}.[10] This value was estimated from the output of all large coal mines of the country. Another point is that some of the coal produced, though

not in any quantity, has resulted in doses that cannot be neglected because of the higher content of natural radionuclides.

Table 3 shows the collective dose and pollution related to coal mining and coal use.[9,11,12] The 1988 electricity production in China was about 50 GW · a, and the corresponding collective dose from stack effluent was as high as 2.5 x 10^3 man · Sv. But there is an even more important dose contributor. As shown in Table 3, the collective dose just from stone- and coal-cinder dwellings is already greater than the above value. In addition, waste water discharged from coal-fired power plants is also a collective dose source that cannot be neglected. For example, certain reaches of the Qiantongjiang river in South China have been found to be apparently polluted with U and ^{226}Ra.

Table 3. Collective doses due to utilization of stone-coal and cinder

source	collective doses, man·Sv·a^{-1}	ref.
Stone- and coal-cinder buildings	$3.5x10^3$	11
Coal-cinder brick* buildings	20.9	12
Exploitation & use of stone-coal	$2x10^4$	9

* the coal is the by-product of a gold mine in the western part of Hunan province.

IMPACT OF NONRADIOACTIVE WASTES

So far, hazardous impact on the environment due to nonradioactive materials released by nuclear power stations has not yet been identified by modern science and its techniques. This is also true of the more than 30 years practice of China's nuclear industry. On the other hand, the environmental pollutions and hazards caused by coal-fired power plants and other coal-burning uses have attracted more and more attention. The sulfur-dioxidepollution in the atmosphere has been one of the most serious environmental problems of the country. It was estimated that sulfur dioxide released from coal burning was around 12 million tons each year. Acid rain has been positively observed by 40 odd environmental monitoring stations, which were positioned from the north and northeast regions, through the central region to the southern part of China. The pH values of rainwater observed were less than 5.6 in the south part of the Changjiang river from 1981 to 1983. In some areas, such as the Sichuan and Guizou provinces, the situation appears to be more serious. Especially, in Chonqing and Guiyang city, where the pH values were as low as 3.32 and 3.70,

respectively.[13] In North China, though the annual average acidity of rainwater is neutral, acid rain still appears in the winter and spring.

It has been found that the causes of mason-pine forest decline in the Nansan region of Chongquing may be mainly attributed to higher concentrations of SO_2 in the air, acid rain, and fog.[14] The fir forest over a large area of the Emei mountains in Sichuan province was also found to suffer seriously from sulfur-dioxide and acid rain.[15]

HEALTH EFFECTS

The development history of the nuclear industry has shown that, unless a major accident takes place, there are no detectable health effects around nuclear power stations. On the contrary, noticeable health effects in the public living near coal-fired power plants have been positively confirmed through epidemiological investigations. An investigation of this kind was carried out in Yangquan district, Shanxi province, where there are large coal mines and large coal-fired power stations. The results suggest that there exists an apparent difference of chronic obstructive pulmonary disease between the downwind and upwind directions of the power stations, and the lung-cancer mortality in mining regions is somewhat higher than that in the urban area and the suburb of Yangquan city.[16] Several other investigations showed that inhabitants who directly burn coal for cooking and/or heating suffer respiratory tract diseases more frequently. Lung-cancer mortality has been found to have a close correlation with the domestic use of coal.[17]

To sum it up, it is very clear from the viewpoint of environmental protection that nuclear plants are superior to coal-fired ones. Coal-fired powerplants and other coal-burning uses create seriousenvironmental problems, whereas no noticeable impact was identified for nuclear plants. Even with respect to the radiation risk, with equal energy output, coal-fired stations are still an order of magnitude higher in risk than nuclear stations. It is well known that coal burning is one of the largest contributors to carbon dioxide in the atmosphere and thus to the greenhouse effect. It is for the above reason that more and more people in China are coming to realize that nuclear energy is a cleaner and safer energy source.

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THE DEVELOPMENT OF ENERGY AND ITS INFLUENCES ON THE ENVIRONMENT

by

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INTRODUCTION

Energy consumption is increasing substantially as the world economy rapidly develops. The influences of energy development on the environment will become more conspicuous. Among them, pollution caused by burning fossil fuels draws the greatest attention from all nations.

Some experts hold that, since the early eighties, a second upsurge of environmental concern has occurred because of the increasing environmental pollution and damage to the ecological balance on a large scale. The first environmental movement occurred between the fifties and the sixties. At that time, environmental pollution in industrialized countries was so serious that it threatened directly the life and security of the people, exerted a tremendous influence on economic development, and caused serious social disturbances. Despite all these disadvantages, however, it appeared only in some factories and districts in those countries. Comparatively, both the pollution sources and their range were more limited. The United Nations held the "Conference of Human Environment" at Stockholm in Sweden at this time. It was a milestone for mankind to recognize the importance of and make efforts for environmental improvement.

In the recent environmental movement, people are more concerned about problems that have an extremely harmful impact on large areas, including the problems of acid rain, ozonosphere destruction, greenhouse effects, etc. These problems attract a great deal of attention in countries all over the world.

Concerned authorities in China have also begun to attach importance to these problems. This is especially true of energy consumption in China, as the main fuels in cities and large industrial bases are coal and other fossil fuels, whereas 75 percent of the energy in the countryside is dependent on biomass energy. Such a pattern undoubtedly exerts a big influence on environmental pollution and undermines the ecological balance. In recent years China has started studying the future of energy development, investigating the need to reform the energy structure and strengthen research in environmental protection, monitoring, and cleaning measures. It has undertaken international exchanges and cooperations and tried its best to draw up a reasonable blueprint for the solution of the all-encompassing energy and environmental problems.

THE DEVELOPMENT OF CHINA'S ENERGY AND CHARACTERISTICS OF CHINA'S ENERGY STRUCTURE

Since the People's Republic of China was founded in 1949, energy production has increased rapidly. In 1980, the national gross output of industry and agriculture was 16.2 times that in 1949. Energy consumption

was 25.7 times. From 1949 to 1980, the average growth rate of the national gross output of industry and agriculture was 9.4%, while that of energy consumption was 11%. In 1987, the gross output of primary energy sources in China reached 910 million tons in terms of standard coal. Among these sources the output of raw coal amounted to 920 million tons, occupying first place in the world. The production of crude oil was 134 million tons, occupying fifth place; electric energy production reached 497.3 billion kwh, occupying fourth place; hydroelectric energy production was 100.2 billion kwh, occupying fifth place; and natural gas production was 13.5 billion cubic meters.

In the year 2000, the planned goal of China's energy production is 1.4 billion tsc of primary energy, and the gross electric energy production will reach 1200 billion kwh, with 240 million kW of installed capacity.

An intermediate to long-term economical and annual energy demand of the PRC is forecast in Table 1 (taken from the first issue of the Chinese *Nuclear Sciences and Engineering*, in 1988).

Table 1. A Forecast of PRC's Intermediate to Long-term Economical and Energy Demand.

Target	Unit	Time				
		1980	1985	1990	2000	2030
Gross National Product	10^8 usd	2736	4597	6600	12030	51990
Annual Energy Demand	10^8 tsc	6.02	8.41	9.91	14.14	34.5
Annual Electric Power Demand	10^8 degrees	3006	4073	5500	12000	51860
Energy Consumption of Output Value	$\frac{\text{tsc}}{10^4\text{usd}}$	22.0	18.3	15.0	11.8	6.6
Proportion of E.P.E. in the Gross Outputof Primary Energy	%	20.6	19.3	21.1	30.5	49.6
GNP/Capita	$\frac{\text{usd}}{\text{person-year}}$	277	439	593	962	3710
Annual Energy Consumption/Capita	$\frac{\text{tsc}}{\text{person-year}}$	0.61	0.8	0.89	1.13	2.46
Annual Consumption of E.P./Capita	$\frac{\text{kwh}}{\text{person-year}}$	304	389	494	960	3700

Note 1. Output value is calculated according to the prices in 1980.

2. At the time of forecast, 1 usd=1.55 yuan Renminbi.

3. Figures in 1990 are those envisaged in "the Seventh Five-Year Plan."

From Table 1, it is clear that the energy demand in 2000 is two times more than than in 1980. In 2030, it will be nearly six times that in 1980. As to the energy consumption per capita, it is very low in our country. It was only 0.8 tsc in 1985, one-fourth of the world average level. To make the living standard of the Chinese people reach the average level of middle-developed countries, the energy consumption per

capita will need to be about 5 tsc, and the gross energy demand will need to reach more than 6 billion tsc—a very hard task.

China is quite rich in coal, petroleum, natural gas, hydro-energy, uranium minerals, and other energy resources. The supply of various energy sources can serve as a base for self-reliance. In particular, coal, of which China has large reserves and a good assortment, serves as the mainstay of our energy consumption. The fuel for 78 percent of our thermal power is coal. Table 2 shows a comparison with other countries (taken from *Energy Statistics Monthly* (US), January 1987).

Table 2. Primary Energy Consumption Constitution in Major World Countries in 1986

	The World	PRC	U.S.A.	Japan	F.R.G.	France	U.K.	Italy
Consumption (10^8 tsc)	108.1	8.088	26.59	5.666	3.783	2.81	2.991	1.902
	Consumption Constitution (%)							
Petroleum	38.0	17.1	43.2	55.8	42.5	43.0	36.2	60.9
Natural Gas	20.0	2.3	22.4	10.2	15.5	12.5	23.5	21.7
Coal	30.0	76.0	23.3	18.8	30.1	10.0	32.4	9.8
Nuclear Power	5.0		6.1	10.3	10.9	32.8	7.5	1.8
Hydraulic Power, etc.	7.0	4.6	5.0	4.9	1.0	1.7	0.4	5.8
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

In Table 2, obviously, one of the prominent features in the PRC, compared with other countries, is that coal is its main fuel. The proportion of coal in China is 2.5 times the world average.

ENERGY SOURCES THAT CONSIST CHIEFLY OF COAL AND FOSSIL FUELS HAVE A GREATER NEGATIVE IMPACT ON THE ENVIRONMENT

In general, the worldwide influence of energy consumption on the environment includes the following areas: emission waste heat and the accumulation of carbon dioxide may affect the climate of the Earth; sulfur dioxide and heavy metals can pollute the environment; petroleum products being transported across the seas can pollute the ocean; and accumulation of radio isotopes and krypton-85 can influence the atmosphere.

The most important influence of energy consumption on the regional environment is injury to the human body, caused by the emission of chemical substances. Secondly, the emission of waste heat also undermines water-systems ecology.

Coal, as well as other fossil fuel, is the energy source causing serious pollution to the environment. An average thermal power plant of 1 million kW expels 1 million tons of soot, more than 60 thousand tons of sulphur dioxide, and 630 kg of benzopyrene, a strong carcinogen, per year. Seventy-three percent of the floating dust and 90 percent of the sulphur dioxide ejected into the atmosphere come from burning coal.

The sulphur dioxide and nitrogen oxide poured into the atmosphere rapidly dissolve in cloud moisture and become the sulfuric acid and nitric acid that leads to acid rain. The accumulation of carbon dioxide and other gases in the atmosphere causes the absorption and reradiation of some of the longer-wave-length infrared radiation, causing thetemperature to increase on the Earth's surface—the so-calledgreenhouse effects. A temperature increase due to this effect appears to be developing. According to the research findings of Professor Zhu Kezhen, late vice-president of the academy of sciences in China, the change of air temperature in the past five thousand years in China has been about 2°C. At a conference, held in Austria in 1985 by the world Meteorological Organization, the World Scientist League, and the United Nations Environmental Bureau, it was suggested that, by the thirties in the next century, the density of carbon dioxide in the atmosphere will have doubled, so that the world air temperature will increase 1.5°C to 4.5°C in fifty years. In such a short period of time, the enormous increase of air temperature will cause part of the icebergs in the Antarctic and Arctic poles to melt with a corresponding increase in the sea level. The increase in air temperature will also expand desert areas, cause migration of the rain fields, increase natural calamities, and decrease the grain yield, bringing great sufferings to mankind.

In our country, owing to a very large population, big gross energy consumption, and our sole reliance on coal, the problem of the atmospheric pollution is very serious. Monitoring data on certain cities in China tells us that in the atmosphere of 89.4 percent of the cities investigated, the density of particulate matter exceeds the state standard. In cities like Chongqing, Guiyang, Changsha, Nanchang, etc., acid rain pollution has appeared and the tendency appears to be increasing. Among the forty cities monitored by a worldwide environmental monitoring system from 1980 to 1984, the five cities monitored in our country—Shengyang, Xian, Beijing, Shanghai, and Guang Zhou—were second, third, fifth, ninth, and tenth, respectively, in the density of particulate matter (Kuwait in the Middle East ranked first in this survey). In the city of Benxi in the Liaoning province, visibility is only 30 to 50 meters nearly half of the year due to the atmospheric pollution. Our country has become one of the most seriously polluted countries in the world.

DEVELOPMENT OF ENERGY SOURCES AND ENVIRONMENTAL PROTECTION MUST BE PUT IN A COMPREHENSIVE ARRANGEMENT

Energy is an industry with a large investment and a long period of cycling in capital construction. To develop energy sources, we must not only consider the demand of satisfying economic development but also the demand of decreasing environmental pollution. It is necessary to make long-term, rational, overall arrangements.

The disadvantages of China's energy structure, which is heavily reliant on coal, is quite obvious. They include shortage of transportation, serious pollution, and a profound and lasting influence on the Earth's climate. So it is necessary to plan the reform of that energy structure according to our present resources before it is too late. A comparatively rational plan is to transform the present energy structure gradually into a pluralized one, taking coal, water, and nuclear as its three pillars, and other energy sources as its supplements.

Hydro-energy: water power resources is an energy source that continually regenerates due to the periodicity of hydrographical circulation. It is one of the cleanest energy sources among the regular primary sources. Our hydro-energy is one of the richest natural resources in the world. The theoretical reserve throughout the country is 6.8×10^8 kW. Of that, 3.78×10^8 kW may be exploited. Up to the end of 1987, the installed capacity of various hydroelectric stations was about 30 million kW and that being

built was nearly 20 million kW. In addition, there are more than 3 x 10^8 kW still to be exploited. The potential in this field is quite large.

To meet the energy demand and decrease reliance on coal as soon as possible, we should adopt the policy of speeding up the development of medium-sized hydroelectric stations (2.5 - 25 x 10^4 kW). The investment per kW of a medium-sized hydroelectric station is about 20 percent higher than that of a large-scale one, but the time required to go into operation is about 50 percent shorter. It has the features of moderate scale, short time for construction, and quick results.

Nuclear energy: China is a country rich in uranium resources. The proven uranium deposits are enough to allow pressurized-water reactor stations of 15 million kW to operate for thirty tears. Moreover, if we begin to develop breeder reactors in time, the use ratio of these resources can be raised sixty or seventy times, and the nuclear energy resources will last hundreds of years. Of course, if in the future nuclear fusion power can be developed, the nuclear energy resources can then probably be considered as infinite.

Nuclear power is an energy source that is safe, economic, and has less of an effect on the environment. In spite of the fact that people have been doubtful about the development of nuclear power after accidents at Three-Mile Island and Chernobyl, as a whole, most of the nuclear power plants in the world have continuously been in safe operation. Nuclear security may be further improved by using the best technical means, operating methods, and operators.

Our country's construction of nuclear power has already started. A pressurized-water reactor station of 300 thousand kW in Qinshan, which was designed, developed, and built by our own people, will be completed and generating electricity in 1990. The electric power of the imported nuclear power station at Daya Bay in Guangdong is estimated to generate 2 x 900 thousand kW of electricity in a parallel net in 1992 to 1993. Besides, the nuclear power plant of Qinshan has been preparing in advance for the second phase of completing a 2 x 600 thousand kW generating unit. According to the present preliminary program, gross installed capacity of nuclear power in China will be 3.3 million kW in 1995, 6–7 million kW in 2000, and about 30 million kW in 2015.

At present the guiding principle of nuclear power development in China has been essentially that of "relying on our own efforts while seeking cooperation from outside." The pressurized-water reactor of 600 thousand kW has been chosen as the main reactor type, so as to quicken the pace of nuclear power development.

Most of the Chinese and foreign experts hold that nuclear power is the most realistic energy source with a bright prospect. Developing nuclear energy at a large scale is one of the fundamental measures for solving energy problems in our country, as well as in the whole world, by the end of this century or the early years of the next century.

In addition, we should pay great attention to the development and use of solar energy, wind power, and other clean energy sources.

TO STRENGTHEN INTERNATIONAL EXCHANGES AND COOPERATIONS

The environmental movement involves a wide range of problems, including vast polluted areas and complex pollutant sources. Some pollutions come from economic activities, others from everyday life. Some come from economically developed countries, others from developing countries. So it is very necessary to

develop significant cooperation throughout the world. We suggest developing international exchanges and cooperations in the following four areas:

1. Strengthen exchanges and cooperations in environmental monitoring and management.

   The environmental monitoring of various countries is an important way to get a clear view of the trends of environmental pollution. Strengthening exchange and cooperation will deepen the monitoring work throughout the world.

2. Strengthen exchanges and cooperations in cleaning measures in environment.

   While strengthening the study and exchanges about acid rain, the deterioration of the ozonosphere, and greenhouse effects, we should vigorously develop the study of cleaning measures for the environment and popularize those with both economical and effective results. Developed countries should transfer modern and low-pollution techniques to the third world.

3. Strengthen exchanges and cooperations with regard to nuclear-power security.

   Any nuclear accident that occurs in the world not only affects environments and population in one's own country but also affects other countries as well. So the nuclear-power security problem has become a central issue of deep concern to the world nuclear industrial circles. It is necessary to strengthen exchanges and cooperations in this field. As the nuclear-power undertaking in our country has just begun, it is especially important to draw lessons from all the previous accidents abroad. In international exchanges and cooperations, we should do all we can to reduce or eliminate the possibility of accidents, with their potential results, and to make our nuclear power plants safe and reliable in operation.

4. Strengthen exchanges and cooperations in the developing technology of clean energy sources.

   Solar energy, wind power, etc. are clean energy sources of great potential. But is is necessary to solve the technical problems of development and use. If we can make good technical progress in this field and carry out effective international cooperation, it will bring tremendous benefit to the people of China and the whole world as well.

ENERGY: THE COIN OF INTERNATIONAL UNDERSTANDING

by

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Energy and agriculture have been the technological hallmarks of civilization from its dimmest beginnings. The myth of fire stolen from the gods recounts the first ever technology transfer activity, and it quite rightly focuses on energy. Even that myth foreshadows the ambivalence mankind has always exhibited toward fire. There is a price to pay for the possession of fire. Fire, the good servant and evil master. Don't play with fire. How deeply energy is engraved in human consciousness!

Now, with a world of five billion souls and heading for double that number, energy commands center stage. Everybody uses, mistrusts, needs, wants, loves, hates, and fears some aspect of energy. Rich and poor, north and south, capitalist and socialist, humanist and fundamentalist—all deal with energy in the most intimate way. The price of oil has an immediate effect on the economy of the West, it can start and stop development in the third world, it leads to wars, it determines the size of cars in Japan, and creates bizarre cities on stilts in the hostile North Sea.

Energy is the great benefactor: it relieves drudgery, it makes agriculture productive, it gives us light and heat. What is the great dream of every young person in the U.S.? To own that certain car. The same dream that informs the citizens of the third world, that leads to impenetrable traffic jams in Mexico City, in Nairobi, in Shanghai, but not yet in Moscow or Kiev. No doubt the unsuspecting Russian will judge perestroika to have been successful when there is gridlock on Pushkin Street. A car is a truly wonderful invention, and the whole world loves it.

Energy is the great polluter: smog, carbon dioxide, acid rain, islands of heat, melting permafrost, ash, nuclear waste. Indirectly energy fuels all the other forms of pollution: agricultural waste, pesticides, the little bits of polystyrene, the huge amounts of just plain trash in search of a final resting place.

Energy knows no boundaries: the oil that is pumped in Kuwait may be used in Japan or in France. The nuclear accident in the Ukraine frightens Danes and Germans. Sulfur from coal-fired plants in England and the U.S. raises angry voices in Sweden and Canada. The greenhouse gases generated in the energy-rich societies may some day impact the entire globe in ways we cannot now fathom.

For our purposes, we can identify four aspects of energy that characterize its uses by society.

1. Resources. These are the familiar reservoirs of oil and gas, the surface deposits and deep seams of coal, uranium-bearing ores, and falling waters. In the future, we may include shales, tar sands, and even sunlight. We consider in this rubric also international commerce, with its political and economic factors that surround fossil and nuclear-energy resources.

2. Technology. This part covers the design and construction of energy-conversion systems from fractional horsepower motors to diesels, fan jets, gas turbines and gigawatt central power stations, pipelines, drilling equipment, tankers, hydro plants, solar collectors, in other words the whole technological infrastructure that has to do with extraction of resources, conversion of energy forms, the protection of the

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environment and health. Included here are the technologists, the people who design, build, operate, and maintain all this infrastructure.

3. Environment. Here we include effluents and other environmental consequences of energy technologies in all their forms. Oxides of nitrogen and sulfur from automobiles and coal-fired plants, nuclear waste, fly ash, reservoir silting, acid rain, noise, thermal pollution of rivers, increases in cloud cover, the consequences of accidents whether they be oil spills, gas explosions, or nuclear meltdowns. In other words, all those consequences of energy technologies that affect the flora, fauna and human well being.

4. Research and Development. Although this category is small in economic terms compared with the immense sums involved in resources or technology, it is not negligible from the point of view of international understanding. Energy-related R&D is by its nature international and as a precursor of technology it carries with it extraordinary leverage for future development as well as huge penalties for inadequate planning or analysis.

Two attributes of energy—its supreme importance in today's civilization and the permeability of national and regional borders to its resources, technologies, and consequences make it truly international. Important and powerful people in all parts of the world are concerned with energy. The educated and the illiterate feel the consequences of energy policies of all nations. The press has developed specialized writers in the field. For all these reasons, and others that flow from them, energy is the subject *par excellence* of international technological discourse. Some of the international effects are constructive and some are destructive. Much can be achieved in international understanding in the name of energy now and in the future, but much harm can be inflicted as well.

Let us examine what has worked, what has brought greater understanding between the developed and the developing nations, what has tended to bring cooperation between developed countries, what bridges are being built.

Consider first the relationship between the developed and developing nations. We tend to think of this as technology transfer from the rich to the poor. And so it is in most cases. For example, the Oak Ridge National Laboratory has since 1982 carried out a lively and diversified program in 30 developing countries funded by USAID. In several countries analyses of energy options and appropriate technologies have been successfully carried out. These studies included institution building, pricing policies, and environmental impacts. In Pakistan, Haiti, and India coal technologies were developed, in particular briquetting in the first two and fluidized-bed combustion in the last. In the Philippines and Liberia rural biomass gasification plants were established; biomass briquetting in Madagascar; solar photovoltaic installations for villages removed from the electric net were placed in the Dominican Republic and in Egypt. On a grander scale a total electric energy efficiency improvement plan was developed for Costa Rica. And so it goes. This particular program has dealt with all forms of energy except nuclear.

In the heyday of optimism about nuclear energy, there were visionary plans to build huge nuclear desalting plants in arid tropical regions. Turning deserts into gardens, it was called, but neither the technology nor the international structure was ready for such giant steps. That does not mean that it will never happen. When nuclear, or fusion, energies become, so to speak, normal sources of power, when an educated world can regard them with reason and calculation, we may well see the rebirth of such enterprises as the agro-industrial complex or some project derivative from it.

As energy technologies are transferred from the developed to the developing states, it follows that education and research will flow in the same channels. It is the hallmark of the most successful developing states in the past (Taiwan, PRC, Korea, India) that they have sent large numbers of their best and brightest

young people to study in western universities and to work in western research laboratories. While many of these students have stayed on to enrich their adopted host country, many have returned to give their homeland a chance to develop and compete successfully and thus improve its standard of living far beyond anyone's expectations. A consequence of this traffic in human intellect was loss of isolation, new connections between countries, better understanding, a model that turns out to be the envy of nations that for one reason or another did not participate in such initiatives. Where education leads the way, research soon follows. Interaction between scientists from different countries must be the most tenacious kind of international connection. And here we see the phenomenon of reverse technology transfer—the story of science and engineering of the past few decades is full of contributions in directions that might appear counterintuitive. On the whole everybody wins in this kind of technology transfer. The country of origin gains some highly trained and motivated people, the host country receives energetic hard working talent, and the young people advance their personal ambitions whether they stay abroad or return home. While energy is certainly not the only technological link between nations, it is often the first to be instituted because its impact is so great on rich and poor alike, and because its importance is so evident even to unimaginative policymakers.

Among the developed countries, among the super-power blocs, among the big four (Japan, the U.S.S.R., Europe, and the U.S.), energy forms a dense web of interactions. Some examples: Soviet reports about Chernobyl have convinced many in the west that the Soviet Union is entering a new phase of candor and openness.

While we are on the subject of nuclear energy, let me cite another example. The whole world is searching for a truly safe power reactor system. Many exchanges between the big four and much coordinated research is under way on advanced light-water reactors, liquid-metal reactors, and gas-cooled reactors. It is not unusual for one country to fund research in another. Light-water-reactor pressure-vessel embrittlement has become a real problem as reactors age. The Soviet Union has developed methods for annealing the pressure vessels that appear to be both effective and efficient. We are now evaluating them in the U.S. On the other hand, the U.S.S.R., in a quest to make their whole nuclear enterprise safe, is trying to find out what makes the U.S. Nuclear Regulatory Commission so effective and will likely copy much of that institution.

Can we say that acid rain is a medium for enhancing understanding between the U.S. and Canada? At first sight, certainly not; it creates nothing but acrimony between neighbors. But, in the long run, we will stop harmful power-plant emissions in the Midwest, and we will probably continue to buy hydro and nuclear electricity from Canada. Emission-free power plants in the U.S. will benefit both countries, and wheeling electric power from Canada to the U.S. will probably be followed by a trans-Canadian pipeline and in the future by exploitation of Canadian tar sands, connecting the two countries in a tight energy network. Can we envision a future where electric power is transported between nations on superconducting transmission lines the way natural gas now flows freely between the Soviet Union and Western Europe?

Between developing nations, we also see connections in the energy arena. While these connections don't always breed better relations or build confidence in the other party's intentions, the overall effect may be positive. Commerce exerts positive influences, concern for the environment and for human health is an even stronger positive motivator. And certainly R&D and energy policy are areas where international connections even across ideological boundaries are firmest. Each country wants to make sure that it is planning wisely for the future, each wants to know what its competitors are doing, what ideas may be bubbling up here and there.

Of course there is a downside. The cruel Iran-Iraq war was mostly about oil, or at least it was ostensibly about oil. History is full of conflicts generated by the absolute need for energy. Hitler's invasion of the

Soviet Union in World War II was in part a drive to secure the Baku oil fields for his war machine. The current unrest in the Middle East has much to do with oil. The French and Germans battled for generations over coal-rich Alsace-Lorraine, and the Russian takeover of Czechoslovakia may well have been partly motivated by the rich Czech pitchblende deposits.

So not all is sweetness and understanding in the international energy game. But, on the whole, the recent evidence leans toward the beneficial. Nations look to other nations in this business, be it as customers or suppliers, as providers of technology or brain power, or as common victims of the environmental consequences of energy.

It is not impossible to imagine a future situation when all of the countries in the world will work together to mitigate the global consequences of the greenhouse effect. Some will plant trees, some will invent new technologies or improve old ones, and some will just cheer and hope. When the survival of a benign climate is at stake, and unity is required, we may just achieve that unity, we may just have to have confidence in our neighbor state and deal responsibly with it so that it will have confidence in us.

They say that the prospect of hanging concentrates the mind wonderfully. Would the prospect of a 10-meter rise in sea level improve international conduct, or would it just result in a mad race for the high ground?

CONCLUDING REMARKS

by

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May I take this opportunity, on behalf of the Organizing Committee, to thank all of the authors who took the time and effort to prepare outstanding papers for this Conference. In addition I wish to express our appreciation to the session Chairpersons, who did such a splendid job of conducting the plenary sessions and guiding the workshops. The summaries they prepared will receive top billing in the Conference Proceedings.

All of us had difficulty making available the time this Conference demanded. However, Senator Domenici and especially Congressman George Brown merit special recognition in this category of sacrifice.

I believe I speak for all of the organizers when I say that I could not be more pleased with the papers presented and discussions held during this Conference.

There appeared to be unanimity on the proposition that energy and environmental problems are following a course which threatens to overwhelm all nations and all peoples unless we take corrective actions, and soon. There also was unanimity on the thesis that many of the global problems require international cooperation and collaboration on a scale never before experienced and that this is a matter of survival.

Now a strictly personal observation, as one who has been involved in nuclear energy affairs for 45 years. It seems to me that nuclear energy, in its most horrible form, not only brought an end to a terrible war but has also served to discourage war between the major powers for more than 40 years, the longest such period in all of modern history, which dates back about 350 years. Nuclear arsenals, obnoxious though they are, have helped buy time for the world to put its political establishment on a path which makes global war less and less probable. This must continue but, in addition, we now need to buy time (50-100 years) to develop environmentally benign energy sources that are affordable and that will help alleviate the instabilities imposed by islands of affluence in a sea of despair. This Conference reinforces my belief that nuclear energy can help mightily to solve that problem. In fact, it appears to be one of the very few realistic options available to us. But we will fail in making this option available if we do not find a way to increase the literacy of the world's people, and especially their leaders, about environmental matters generally and about the nuclear-energy option in particular. We must find ways to provide factual information with impeccable honesty and high credibility. I am hopeful that the information generated by this Conference, widely disseminated, will help to do that and also to foster such Conferences in the future.

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ABSTRACT

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