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PROCEEDINGS OF THE 2nd MIT INTERNATIONAL CONFERENCE ON THE NEXT GENERATION OF NUCLEAR POWER TECHNOLOGY

October 25-26, 1993

Massachusetts Institute of Technology
Cambridge, MA 02139-4307

Sponsored by
The Program for Advanced Nuclear Power Studies
Professor Michael W. Golay, Chairman

DISCLAIMER

TABLE 1

AGENDA

2nd MIT INTERNATIONAL CONFERENCE ON THE NEXT GENERATION OF NUCLEAR POWER TECHNOLOGY

25 October 1993

8:00am Registration

8:45am Introductory Remarks: Prof. Michael W. Golay, Conference Chairman

9:00am Session 1

What Role Should Nuclear Power Play, and What Would Life Be Without It?

Author: Michael W. Golay, Nuclear Engineering Dept., MIT
Respondent: Dr. Robert H. Socolow, Director, Center for Energy & Environmental Sciences, Princeton University

Use this session to focus upon advanced reactors and their possible future roles. Outline how the succeeding sessions focus upon important questions, all of which are related to the last session, regarding what our future nuclear strategy should be. This session should include energy markets that can be served by nuclear power, and averted environmental effects that otherwise would be imposed by competing technologies. Concerning global warming, use this session to explore topics including time scales for responses using different technologies to postulated global warming, energy products from nuclear reactors (e.g., hydrogen), worldwide penetration of nuclear-based energy reactors for developing countries, fuel supply constraints and implications. Discuss factors that may limit the role of nuclear power.

10:30am COFFEE BREAK

10:50am Session 2

How Long will the Current Nuclear Power Reactors Operate?

Author: Dr. Andrew Kadak, President, Yankee Atomic Electric Co.
Respondent: Mr. Mason Willrich, Pacific Gas and Electric Enterprises

Use this session to explore topics including factors of economic performance, relicensing and life extension for the existing reactors, and implications of a prematurely reduced nuclear industrial base as it would affect personnel supply, utility interest in nuclear power, the funding base and time horizons for technological innovation.

12:30pm LUNCH

1:30pm Session 3

Can Nuclear Power Gain Public Acceptance?

Author: Dr. Roger Kasperson, Clark University, Worcester
Respondent: Prof. Thomas Hughes, University of Pennsylvania at Philadelphia

Use this session to explore factors affecting energy technology preferences and aversions, particularly among the general public and among influential minority groups (e.g., environmentalists). Try to distinguish the roles affecting technology acceptance or rejection, of competition for political power, of public attitudes toward organizations identified with different energy technologies and of public judgments of the technologies themselves.

3:00pm COFFEE BREAK

3:20pm Rapporteur's Report – (Rapporteur: Prof. Kent Hansen, Nuclear Engineering Dept., MIT)

FOREWORD

Structure and Goals of the Conference

The Second MIT International Conference on the Next Generation of Nuclear Power Technology is organized by the MIT Program for Advanced Power Studies. The Program is an activity which we began at MIT in order to make a contribution for the success of the next generation of nuclear power. In doing this, we believed that there were important questions where we had relevant expertise at MIT, and that it was appropriate for us to play a leadership role so that any next generation technologies were developed, as well as possible, and for us to provide educational opportunities for students who might wish to participate in such work.

About five years ago we decided that in addition to research and student education that it was important also for us to become involved in the public debate concerning nuclear power. The reason for this was that we felt that there would not be a second generation of nuclear power, if our society were not to reach an effective consensus that there should be one, as well as, a consensus regarding what form it would take. We felt that at a university we had the opportunity to provide a forum for that kind of consensus-oriented debate, which we did not see occurring elsewhere.

Rather, the kinds of discussions of nuclear power which were visible were generally organized to attract an audience which would agree with the organizers, but where one did not encounter clashing views that would eventually lead to an effective consensus. So, we initiated a series of conferences focused upon the future of nuclear power. This Conference is our second.

Our goal was to try to attract a variety of points of view from well-informed people to debate issues concerning nuclear power. Hopefully from that process a better understanding of what we should be doing will emerge. We note that this meeting was sponsored by the U.S. Department of Energy and also the Electric Power Research Institute. I believe that they share our view that having this kind of discussion is beneficial for everyone.

In organizing the Conference we tried to learn from the previous one. So, we continuously made an effort to see to it that the arguments for the alternatives to nuclear power were given abundant time for presentation. This is ultimately because nuclear power is going to have to compete with all of the energy technologies. Thus, in discussing our energy strategy we must consider all of the alternatives in a reasonable fashion.

Everyone participating in the Conference did so by invitation. The structure of the conference was explained in the invitation letter which everyone participating had received. The structure used has seven sessions (see Table 1). The first six led up to the final session which was concerned with what the future nuclear power strategy should be. Each session focused upon a question concerning the future. None of these questions has a unique correct answer. Rather, they address topics where reasonable people can disagree. In order to state some of the important arguments for each session's question, we used the combination of a keynote paper followed by a respondent. The respondent's paper is not necessarily included to be a rebuttal to the keynote; but rather, we recognized that two people will look at a complex question with different shadings. Through those two papers we hoped to get out the most important arguments affecting the question for the session. The purpose of the papers was to set the stage for about an hour of discussion. The real product of this Conference is that discussion.

We taped the discussion to use in producing the Conference Proceedings. These consist of the papers and the associated discussions. The same format was used in our first Conference, and the feedback was that this format worked reasonably well. Those Proceedings are available for anyone who will find them of interest.

The constituencies that we went to for the participants of this meeting are:

- People who are critical of nuclear power, particularly as it is used in the United States;
- People who are involved in the nuclear power enterprise within the United States;
- People from other countries who are involved in their own nuclear power enterprises; and
- Scholars of society and technology, people who are particularly interest in socio-technological controversies and the development of technologies.

Table 1 (continued)

3:50pm Session 4

What Role Should Renewable Energy Technology Play; What Would Life Be Like With Them?

Author: Dr. Robert Williams, Center for Energy & Environmental Sciences, Princeton University

Respondent: Profs. Lawrence M. Lidsky and Steven M. Cohn, MIT

Use this session to explore the status and promise of various renewable (i.e., solar) technologies. What is the reality, expectation, hope? What roles could the renewable technologies play in supplying energy worldwide? What factors might limit their penetration? Is their promise sufficiently great and confident to justify letting the nuclear option collapse if one is concerned that global warming is a serious threat?

5:10pm ADJOURN

6:30pm Cocktails, Dinner and Speech
Mr. E.C. (Tip) Brolin, U.S. Department of Energy

26 October 1993

9:00am Session 5

What to Do About Nuclear Weapons Proliferation, and Do New Reactors to Consume Plutonium Make Sense?

Author: Dr. Hal Feiveson, Center for Energy & Environmental Sciences, Princeton University

Respondent: Dr. Robert Budnitz, Future Resources Associates

Use this session to characterize the nature of the plutonium inventory problem. How much is there? Where is it? How fast could it be sequestered securely or consumed? What are the attractive options and strategies for accomplishing these goals and their drawbacks? Would Pu-burning reactors be valuable for this? What are the implications of failure?

10:30am COFFEE BREAK

10:50am Session 6

What Will Happen to Our Nuclear Wastes?

Author: Mr. Tom Isaacs, Lawrence Livermore National Laboratory

Respondent: Ms. Susan Wiltshire, Author of Current League of Women Voters Nuclear Waste Primer

Use this session to explore topics including monitored interim storage, institutional arrangements and public trust needed to permit terrestrial disposal/storage, burning of nuclear wastes.

12:30pm LUNCH

1:30pm Rapporteur's Report – (Rapporteur: Prof. Kent Hansen, Nuclear Engineering Dept., MIT)

2:00pm Session 7

What Should Our Future Nuclear Energy Strategy Be?

Author: Prof. Neil E. Todreas, Nuclear Engineering Dept., MIT

Respondent: Prof. Gene Rochlin, University of California, Berkeley

Use this session to explore topics including potential nuclear futures, necessary performance requirements for advanced reactors, prospects for currently active concepts, challenges not being met by them (e.g., reduced human error, advanced computer control, fuel cycle issues), implications of continued social rejection, conditions necessary for retaining a nuclear power option, implications of not meeting them.

3:30pm Meeting Summary – Prof. Michael W. Golay, Nuclear Engineering Dept., MIT

4:00pm ADJOURNMENT

In inviting these people here we selected individuals who are unpredictable but thoughtful. By unpredictable what is meant is they do not have a well stated position which one would expect them to simply come to repeat and defend in this forum. By thoughtful we mean people who would be willing to listen and perhaps change in response the arguments of others. From this mix of individuals our hope was to have a discussion which would be rich and provocative, and of value and interest to anyone who would read it.

In moderating the discussion following the papers we recognized people in turn at their requests to speak. We asked that those who had spoken once in a particular session wait until others who had not had a chance to speak cease to volunteer.

The invitations were arranged such that the Conference would not be portrayed in the media.. We did this deliberately in order that the participants would feel free to speak their own ideas. The participants were not invited to represent their companies, their own constituencies, or whatever pressure groups they might have come from. In the Proceedings we identify the speakers according to the general background from which they come, but we do not do so individually. This was done in order to obtain a participant's ideas and not necessarily those of his organization.

Everyone was asked to state his ideas and carefully listen to others. We hoped that they would meet people in this Conference whom they would not normally encounter, and that they would appreciate ideas which they would do not normally run into, as well.

We hope that this Conference was an opportunity to think and work together, and hopefully also to have a good time. By all appearances we met this goal.

Prof. Michael W. Golay
Director, Program for Advanced Nuclear Power Studies
Massachusetts Institute of Technology

ACKNOWLEDGMENTS

We acknowledge the generous funding of this Conference by the U.S. Department of Energy (DOE) and the Electric Power Research Insitiute (EPRI). Without this funding, the Conference would not have taken place.

The Conference was organized by the Director of the Nuclear Engineering Department's Program for Advanced Nuclear Power Studies, Professor Michael W. Golay. All Conference sessions met at the Cambridge Marriott Hotel, Cambridge, Massachusetts. The Conference staff were supported by that of the hotel. The Executive Assistant in charge of organizing the Conference, with responsibilities for all logistical and publicity matters was Paula J. Cornelio. She was aided valuably by several MIT graduate students, including Sarah Abdelkader, Joseph Bambenek, David Freed, Anthony Hechanova, Antonia Korzan and Brett Mattingly. In additional to her service during the Conference, Ms. Abdelkader served as Editorial Assistant in editing the *Proceedings*, which were prepared for publication by Ms. Cornelio. The *Proceedings* were published by the MIT Graphic Arts Service.

As it was organized by invitation only and involved a substantial amount of thoughtful discussion, the Conference was made possible only with the enthusiastic participation of the authors and attendees.

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OPENING REMARKS

Prof. Mujid S. Kazimi

Head, Nuclear Engineering Dept., MIT

I am pleased to welcome you on behalf of the Department of Nuclear Engineering to this Second International Conference on the Next Generation of Nuclear Power Technology. For nearly ten years now, the Department has held the view that one of its primary research objectives should be the development of a better understanding of the technical and social frames of reference that will guide the selection of the next generation of reactors. In view of the variety of more popular causes in the U.S., such an objective was not an attempt to gain favors in Washington or Wall Street or even Madison Avenue, but rather the result of a conviction that at a leading university there must be a place for studying and debating the issues surrounding each of the long-term energy supply options, not only among the technologists with the various ideas, but also among the other stakeholders in the energy and environment debate.

We also believe that this is an appropriate time to seriously address the issues of future reactors. For fifty years after the initial demonstration of the controlled fission chain reaction, it appears that the first generation of reactors has achieved nearly all it could be asked to do in providing electricity to the world. It is evident today through 425 reactors of varying sizes and designs, operating in thirty different countries, that the atomic reactor is a major fuel resource that can be used for centuries to come. Yet, it is not clear how it will fare over the next fifty years. It is my belief that if the world is to enjoy a sizable, not an anemic economic growth as we have seen of late, nuclear power will have to play a major part in providing the needed energy. But the extend of that part is fully dependent upon the comparative standing of power from fission reactors to other fuel sources in terms of economic performance, environmental desirability, and public support. These, in turn, depend on the safety features, waste management, and regulatory processes that will be associated with the new reactors.

There are the issues I hope this Conference will illuminate. This is not small task, but then this is a group especially equipped to discuss such issues. I know you will find the correct answers, and I look forward to your deliberations.

SESSION ONE

WHAT ROLE SHOULD NUCLEAR POWER PLAY, AND WHAT WOULD LIFE BE WITHOUT IT?

Michael W. Golay

Massachusetts Institute of Technology

RESPONSE:

THE WEAPONS SHADOW OVER THE FUTURE OF NUCLEAR POWER

Robert H. Socolow

Princeton University

INTRODUCTION

Session 1 – What Role Should Nuclear Power Play, and What Would Life Be Without It?

Nuclear power is easy to discuss with others because everyone has a point of view about it. However, it was necessary to make the discussions of the Conference orderly. For that reason the initial session of the Conference was used to try to focus the disparate viewpoints upon some of the more important topics which will affect the future of the technology, and to place this future in the context of the broader energy debate.

These topics include plausible future energy needs, energy markets which nuclear power might serve, and the implications of global warming and nuclear weapons for the future of nuclear power. Other important topics are the roots of the social debate over nuclear power (at least within the industrialized countries) and the linkage of that debate to questions of trust of institutions and to the anxiety generated by the chronic threat to society posed by the existence of nuclear weapons.

These topics are related to each other and their concatenation is very complex. That is partially why nuclear power is an interesting subject to study, and a difficult technology to use successfully. The initial session of the Conference is used to initiate the energy debate of the Conference, and to set the stage for the sessions to follow.

WHAT ROLE SHOULD NUCLEAR POWER PLAY, AND WHAT WOULD LIFE BE WITHOUT IT?

Michael W. Golay

INTRODUCTION

The purpose of this paper is to set the stage for the discussions of the Second MIT International Conference on the Next Generation of Nuclear Power Technology. I describe the current situation of the nuclear power enterprise worldwide; discuss trends in nuclear technology innovation, including strengths and weaknesses of current efforts; provide a perspective upon important factors likely to affect future use of nuclear power, including concerns about the possibility of significant global warming; draw attention to the further implications of discontinuing use of nuclear power and I suggest a role for the technology to play in the future.

THE CURRENT STATUS OF THE NUCLEAR POWER ENTERPRISE

Worldwide there are approximately 412 nuclear power plants in operation, consisting of 236 PWRs, 88 BWRs, 38 gas-cooled reactors, 31 heavy-water moderated reactors, 15 graphite-moderated water-cooled reactors (all in the former Soviet Union) and 19 of other designs (*Nuclear News*, 1993).

Today nuclear power provides approximately 22% of electricity in the United States, 25% in the industrialized nations, and about 17% worldwide (*Nucl. Eng. Intl.*, 1992). Its only energy product is electricity. For the United States it takes second rank (over hydroelectric energy) as an electricity source (USDOE, 1991), with coal fueled technologies being the most important—providing approximately 54% of the total. Since electricity accounts for 44% of gross U.S. fuel consumption we see that nuclear power typically is economically significant, but not of crucial importance nationally and internationally.

Exceptions are found in more densely populated countries (e.g., Belgium, France, Japan) which have had national policies of restricting petroleum imports via promoting nuclear-based electricity consumption. For most countries (the major exceptions are China, India, the former Soviet Union, Canada and the United States) indigenous fossil fuel resources are small, and nuclear energy is attractive both strategically and economically. Elsewhere nuclear energy must compete economically with locally produced coal and gas-fueled technologies.

Nuclear power plants have never been built in Australia, Denmark, and Norway. Today the effort to expand the nuclear energy sector has reached an impasse in most of the other industrialized countries. At least informal moratoria on new plants exist in Austria, Germany, Italy, the Netherlands, Spain, Sweden, Switzerland and the United States. In these countries the current greatest challenge to the nuclear power industries is to operate the existing plants economically in order to stave off premature shutdowns. Recent examples of such shutdowns are found in the United States, the United Kingdom, and Italy.

Japan and France each continue to order a new nuclear power plant every two years, of so. Doing this keeps their national nuclear industrial firms in business, and provides a modest, but treasured, amount of work for international suppliers. However, this level of business activity is not generating profit streams large enough for the firms involved to undertake technological innovations on a serious scale.

The countries most likely to generate orders for new nuclear power plants in the immediate future are Korea and Taiwan. They have had sustained respective electrical energy demand growth rates of approximately 13% and 9% [*Nuclear News* (Nov. 1992), (Oct. 1992)] for several years. Each is imminently planning to order two new units, reflecting this vigorous growth. The major nuclear power-related problems facing these countries include those of finding sites for new stations, funding their investments and formulating an effective strategy for becoming more self-sufficient.

China has also built two new plants during recent years, and may be on the verge of a large expansion of its civilian nuclear power program. What is done in China will be especially important regarding global warming (should it turn out be an important concern), as indigenous coal constitutes the main alternative near-term electrical energy fuel for that country. With 20% of the world's population, and with recent economic growth rates similar to those of Taiwan and Korea that country is poised to contribute greatly to future fuel demands, and perhaps to new emissions of greenhouse gases (henceforth in this paper in the interest of brevity qualifying remarks concerning the tentative nature of global warming worries will be omitted when it is discussed, but these omissions are not intended to imply a conclusion that global warming concerns are clearly well-founded; rather my discussion simply takes into account the fact that many people are worried and may demand a global policy response). Thus, the future development of nuclear energy may depend strongly upon the degree to which it is attractive to China to expand its nuclear electricity supply sector. It will also depend upon Chinese success in building and operating its nuclear power plants well.

In addition, Egypt, Indonesia and Turkey have expressed tentative interest in obtaining their initial nuclear power plants. However, to-date the commercial conditions necessary to permit these interests to advance to a more serious stage have been absent. These interests raise special concerns as it can be difficult for a newly industrializing country to establish the needed cultural conditions for successful nuclear power use. In addition to the problems of finance and developing an adequate cadre of technicians, success with nuclear power requires that the people associated with a nuclear power plant have the attitudes and values required for safe operations. If these practices are too different from those brought to other public and occupational safety problems in the society it is likely that the required level of nuclear safety compulsiveness cannot be sustained, with low operational availability and accidents being the likely result. The operational record of nuclear power in India provides a relevant example. Sometimes the practices of a society in protecting its citizens from traffic accidents can be used as an indicator of whether it is ready to use nuclear power.

Some (e.g., Wakabayashi, 1986) have suggested that a new generation of reactors could be built which would be so simple to operate that they would be suitable even for risk-accepting, technologically unsophisticated societies. The usual approach taken in attempts to produce such a concept is to reduce the number and stress levels of human actions needed in response to postulated accidents, thereby increasing the expected human reliability of accident responses. A problem is that even were accident response reliability made perfect (this has not been accomplished) additional opportunities for human failures would remain which on-one has a plan for eliminating. These include equipment fabrication and construction errors, maintenance errors and gratuitous errors of commission (e.g., unnecessary actions which make a situation worse) during operations. Despite the optimism generated for error-proof nuclear power plants no-one has yet developed such a reactor concept, or a even theory which would guide designers to conceive one.

The question of whether a very "user friendly" nuclear power plant could be developed is especially important for determining whether nuclear power would permit an effective mitigation of postulated global warming. This is because in the long run the emissions of greenhouse gases and changes of land uses thought to contribute most to warming would likely be caused as currently unindustrialized countries come to "Western" levels of prosperity. Thus, the ability of these countries to use the nuclear technologies reliably and safely would strongly affect their penetration into their energy markets. At the moment the prospects for creating such reactors are not promising, however, the option of having reactors built and operated by foreign organizations might be a feasible option.

It is widely recognized that safe operation of the existing nuclear power plants throughout the world is essential to the future of nuclear power. The ability to do this is most in doubt in the former east European Communist countries, which operate a total of 50 power reactors [35 PWRs of Soviet design, termed VVERs; and 15 RBMKs, of which the Chernobyl 4 reactor is an example (*Nuclear News*, Sept. 1993)]. All of the RBMKs are in the countries which comprise the former Soviet Union. These reactors all fall short of "Western" standards of safety in terms both of hardware and operational practices. Factors of low safety levels, identified previously regarding hardware include low-capability and low reliability reactor safety systems, absence of reactor containment buildings in many plants, small seismic design margins and poor reactor system materials (Berke, 1993).

Operational safety problems have included incomplete operational procedures, pervasive failures to adhere to the existing regulations and procedures, and optimistic occupational safety attitudes. Since the collapse of Communism these factors have been exacerbated by low rates of spending for plant maintenance and improvements, increasingly poor staff salaries and concomitant low morale, unstable governments and uncertain safety regulatory systems, and decreased ability of countries other than Russia to have easy access to the technical expertise needed for high quality operations. Because of their current poverty and needs for energy the governments of these countries have all decided to continue operating their existing plants, despite their clear faults.

All of this adds up to a very high likelihood of a serious reactor accident in the near future. The severity of this situation is widely recognized internationally, but has generated little concrete response to-date. Isolated efforts to provide nuclear operations assistance have been mounted by Sweden and Germany, among others. However, relative to the size of the problems which exist the that international reaction to this problem has been almost a nullity. Perhaps this will change, but at the moment the collective behavior of the "Western" states appears to reflect judgments that their own nuclear power plants would be able to continue to operate in the event of a serious accident in eastern Europe, and/or that their own plants are sufficiently unimportant that it would be tolerable if they were to be shutdown following an accident. The experience in most industrialized countries following the Chernobyl reactor accident provides some basis for such judgments.

Overall the situation of the nuclear power enterprise worldwide is one of stasis, and heading toward decline. Within most countries greatest concern is given to operating the home reactors well, and to some efforts to learn from and improve the operations of reactors elsewhere (e.g., witness the maturation of the U.S. Institute for Nuclear Power Operations (INPO), and the recent creation of the World Association of Nuclear Operators (WANO)). With the exception of prosperous countries in eastern Asia factors of political controversy and slow economic growth have resulted in a very low rate of new plant ordering, and in the investments in technological innovation staying modest. The result is that the nuclear power infrastructure in most industrialized countries is weakening as new organizations choose not to enter the nuclear energy business sector, as fewer firms choose to stay in it, as operating plants begin to be retired prematurely and as bright young people and the universities which educate them direct their efforts elsewhere. This is a positive feedback, critical mass system, where the departure of each player in the system weakens the ability of the remaining players to function. In most countries the nuclear power industries can likely continue to function successfully for another decade or two (the time scale for retirement of many of the existing plants). However, unless the social acceptance impasse which operates in most nuclear power countries to prohibit new plants is broken the prospects for much wider use of the technology in the immediate future appear to be poor. The major exceptions to this trend are found in eastern Asia.

THE ADVANCE OF ADVANCED REACTORS?

In the First MIT Conference (Golay, 1990) I characterized the worldwide efforts in nuclear power plant technology innovation as being focused primarily upon either improvement of safety or economic performance, with the other class of performance entering the technology optimization problem as a constraint—one of minimal acceptable performance. For example, a successful plant can only be made as safe as economic competition will allow, or can be made more economical only to the extent that society will tolerate the possibility of accidents of all types. The technology optimization problem is intriguing because many of the optimization factors involved are understood only poorly, and their importance changes over time. However, the overall optimization problem remains as described here.

Of the 16 reactor development projects listed in the First MIT Conference, 11 remain vital today (see Table 1.1), and five have since been terminated. Of these three are of the safety-oriented type. Thus, the level of effort worldwide for nuclear power technology advancement is slackening and more so with the safety-oriented concepts than with the economically-oriented ones. As this has been occurring the some of the surviving reactor concepts are being carried to a higher level of design detail, with a increasing scale of activity (see Table 1.1).

As in 1990 the great bulk of funds worldwide are going into developing the evolutionary concepts, while the attention of the world's public is being drawn to the safety-oriented concepts. The latter concepts are very clever, and offer the potential for significant safety improvements, but in most cases they are not being pursued at serious levels of vigor. As with

Table 1.1

CURRENT ADVANCED REACTOR DEVELOPMENT PROJECTS

EVOLUTIONARY REACTORS (Economic Performance-Oriented Concepts)

- Light Water Reactors
  - ABWR [Japan (Hitachi, Toshiba), United States (General Electric)] [1, 3]
  - APWR [Japan (Mitsubishi)] [4]
  - System 80+ [United States (ABB-Combustion Engineering)]
  - European Pressurized Reactor [France (Framatome), Germany (Siemens)] [3]
- Liquid Metal-Cooled Reactors
  - European Fast Reactor (France, Germany, United Kingdom) [2]
  - Monju (Japan)
  - Superphenix (France, Germany, Italy)

PASSIVE SAFETY FEATURES (Safety Performance-Oriented Concepts)

- Light Water Reactors
  - SBWR [United States (General Electric, with several international participants)] [4]
  - AP 600 PWR [United States (Westinghouse, with several international participants)] [3]
- Gas-cooled Reactors
  - Modular High Temperature Gas-Cooled Reactor [United States (General Atomic)] [2, 4]
- Liquid Metal-Cooled Reactors
  - Integral Fast Reactor [United States (Argonne National Laboratory, General Electric)] [2, 4]

[1] = Under construction
[2] = Under political assault.
[3] = Increased level of effort relative to 1990
[4] = Decreased level of effort relative to 1990.

many topics of public interest, the gulf between perception and reality is large. Electric utility companies worldwide are saying consistently that improved economics, consistent with safety is the highest priority.

As in 1990 the great bulk of funds worldwide are going into developing the evolutionary concepts, while the attention of the world's public is being drawn to the safety-oriented concepts. The latter concepts are very clever, and offer the potential for significant safety improvements, but in most cases they are not being pursued at serious levels of vigor. As with many topics of public interest, the gulf between perception and reality is large. Electric utility companies worldwide are saying consistently that improved economics, consistent with safety is the highest priority.

Factors which may explain some of these trends include the following: the worldwide economic recession, with its corresponding increase of competitive stress upon firms, including electric utility companies; a decline of public interest in questions relating to energy supply, including nuclear energy; and a growing belief that improvements in nuclear power plant hardware are unlikely by themselves to break the current moratoria on building new plants in many countries. If these factors are as important as they appear to be the prospects that the safety-oriented concepts will be pursued to completion appear to be dim. Utility companies in China, Finland, France, Japan, Korea and Taiwan are at least at the stage of expressing interest in building plants of the advanced evolutionary type. At the same time the absence of a utility company worldwide offering to host the construction of one of the safety-oriented advanced plants is the clearest evidence of the tentative interest in this class of concepts.

FACTORS AFFECTING THE FUTURE GROWTH OF NUCLEAR POWER

The future growth of nuclear power will depend upon several factors, which include the following:

- The attitudes of different constituencies, each of whose consent is necessary for a nuclear power expansion—these include utilities, critics, investors and the general public;
- The degree of benefit perceived from nuclear power, where the experience to-date has indicated that providing air pollution-free electricity is insufficient to engender much appreciation; whether potential mitigation of global warming will be more valued remains to be seen;
- The degree of risk perceived from nuclear power—this surely depends most upon the quality of the actual nuclear power operating record, but also upon the degree that advanced reactors are perceived to improve upon the evolutionary technology, and likely upon the level of peril felt from nuclear weapons (this last factor could be influenced by the degree of stability attending the end of the cold war, and the extent of recent nuclear weapons proliferation);
- Progress in reducing concerns over the perils of nuclear wastes.

Of particular interest in this list are the role of nuclear power critics, particularly in the United States, and their concerns about the possibility of global warming. In most countries opposition to nuclear power is led by determined minorities, or skeptical elites (to quote Alvin Weinberg) who act as gatekeepers controlling whether nuclear power projects will go forward. They do this by using various means of political expression to create uncertainty about the project costs, and to increase them where possible. The legal and regulatory systems of the United States and Germany provide unusually abundant opportunities for such opposition, and it has been very effective to this point.

However, in some countries portions of that constituency have become convinced that global warming is a serious problem requiring a strong response. While preferring to rely upon renewable energy technologies and efficiency improvements to mitigate global warming some individuals from such groups have suggested that eliminating nuclear power as an available energy option would be unwise. However, this view does not translate into encouragement for building new nuclear power plants, with the result that the nuclear infrastructure continues to decay in the absence of new orders.

Conceivably concerns about fossil fuel burning will eventually render an expansion of nuclear power possible. In light of this possibility it is interesting that none of the current advanced reactor projects is directed toward addressing the requirements of global warming mitigation. Such a reactor would be safer, more economical, easier to operate, of large capacity and a breeder reactor. Large unit capacity of the nuclear power plants is likely required in order to be able to supply reasonably anticipated demands with a reasonably small number of plants.

An important aspect of any response to global warming would be its ability to supply energy to the 80% of humanity currently living outside the industrialized world and their progeny. This population much more than that of the currently industrialized countries will determine how severe any global warming will become. Presumably they would enjoy becoming economically prosperous, and in doing so could greatly increase the rate of greenhouse gas emissions. Thus, their needs and effects must be considered in any plan to mitigate global warming. Doing this would require finding ways to satisfy their energy needs less. These needs are currently supplied by fossil fuels, especially petroleum; and some biomass burning (e.g., using animal dung and wood).

Some mix of renewable and nuclear technologies might be able to supply such energy needs successfully. The nuclear contribution could be made in the form of electricity once a country reached a stage of industrialization which would economically justify building an electrical infrastructure of sufficient capacity, and it could be made via hydrogen production from water for cases where electricity would not be an attractive energy form. In countries where the social attitudes are not compatible with the safety and reliability demands of nuclear technology it might be feasible (but not easy) to operate power reactors using foreign crews. However, it might be preferable to supply such countries with hydrogen produced in the industrialized countries. Factors of economics, political stability and cultural attitudes would be important determinants of the best policy.

A requirement for breeder reactors in any response to global warming is driven by the likelihood of depleting low cost uranium resources. Exactly when and how any mineral resource is likely to become depleted is debatable. For a fuel resource it depends upon cumulative energy demands for the fuel, and improvements in fuel consumption and production technologies. For nuclear electricity cumulative demand will depend upon such factors as the worldwide distribution of economic activities (influenced strongly by world population growth and the degree of industrialization in various countries) and the costs of the competing fuels and energy technologies. For cumulative uranium production important determinants of how much ore can be produced economically will include discoveries of new resources, cumulative amounts of uranium extracted and ore extraction technology innovations.

A recent sensitivity analysis (Schenler and Golay, 1992), which is summarized in Attachment A, examined how quickly currently identified uranium resources would be consumed should nuclear power technologies be employed vigorously worldwide, as in a practical response to global warming concerns. In this work the energy demand model of Edmonds and Reilly (1986) was used to estimate worldwide energy demand growth subject to assumptions of vigorous energy demand management actions worldwide, world population growth to 11 billion persons by 2020, a strong increase in worldwide economic activity, with increased electrification, and a slow growth of the nuclear share of the electricity market share (see Attachment A, Tables 1.2 and 1.3).

The resulting nuclear electricity demand was then assumed to be supplied by different mixes of fuel burner (LWR) and breeder (LMR-IFR) reactors. It is seen using burner reactors that the currently identified low cost (<$130/kg-U) resources would be consumed in about 20 years; and, extrapolating the results, that they would be consumed using breeder reactors in about a century. These uranium consumption time scales are not strongly sensitive to modeling assumptions. The results indicate that a serious nuclear response to global warming would require—sooner than later—heavy use of breeder reactors and a greatly expanded effort to produce low cost nuclear fuel. From that perspective the current focus of nuclear technology innovation with marginal economic improvements and gaining public acceptance is not strongly linked to the problems of global warming mitigation.

The liquid metal-cooled reactors (LMR) are the only breeder reactors listed in Table 1.1. Each reactor concept addresses some of the requirements listed above, but none addresses all. In particular the safety-oriented breeder, the Integral Fast Reactor (IFR), is conceived in low capacity (130 MWe) modules. The economically-oriented LMRs are trying to become economically competitive, use fewer passive safety features but are of large capacity (e.g., 1200 MWe). None is conceived to be used in technologically primitive societies. Also, technologies to produced hydrogen electrically or thermally are advancing only slowly. This is because the near-term agenda for nuclear technology innovation is dominated by concerns for improving economic performance and/or breaking the social impasse against expanded use of nuclear power.

LIFE WITHOUT FISSION

Whether to take seriously the prospects of life without fission energy depends upon one's location. The preceding discussion makes clear that in many parts of the world nuclear energy has provided satisfaction and people are eager to use more. Elsewhere, it has been less satisfactory, and may be facing a decline. In order to consider what life would be like without it one need only examine places where it is not being used. These include a few industrialized countries (e.g., Austria, Italy, Denmark) and most of the non-industrialized ones.

In such countries one beholds greater use of fossil fuels, particularly petroleum; and negligible use of renewable technologies except for domestic niche uses like cooking and some water and space heating. The greatest prospects for the future are more of the same - as long as the available fossil fueled technologies remain environmentally acceptable, more convenient and less expensive than the alternatives from the viewpoints of the energy consumers.

Driven by economic factors, improvements in energy end-use efficiency occur today to the extent that high initial investment costs and inconvenience do not discourage them. We can expect this to continue to be true.

Renewable energy technologies can be expected to penetrate existing energy markets to the extent, also, that factors of cost and convenience permit. The main factor which could discourage such penetration is political opposition which could conceivably arise as these technologies reach the stage of widespread use. Such opposition might be motivated by the environmental and safety effects of these technologies. For example, the solar energy technologies are very diffuse and land-intensive, can cause rapid topsoil erosion and ecosystem change and can be hazardous to workers (as with biomass farming).

Whether social opposition to the renewable technologies will arise remains to be seen, but the transition of any subject from a cherished, but distant icon to being part of routine reality typically causes some disillusionment among the initial admirers. This is true with politicians, lovers, new cars and new technologies. Current litigation to harass development of geothermal energy resources on the island of Hawaii may be a harbinger of this trend.

Any technologies which are to play a serious role in meeting energy needs will have to be used at industrial strength. Symbolic applications such as placing solar water heaters atop public buildings will remain valuable for garnering the support of sympathetic political constituencies, but will be irrelevant in meeting global energy needs. During recent years important constituencies in many industrialized countries have resisted new large industrial projects, particularly land-intensive ones. Thus, whether renewable technologies will be accepted readily is likely to hinge upon the degree that current preferences expressed for them in many countries are actually implicit complaints about modern society as opposed to being serious technological judgments. To the extent that they are the former the prospects for the renewable technologies may be no brighter than for other energy technologies, even when they are economically attractive. As time passes it will be interesting to watch the data arrive.

THE PROPER ROLE FOR NUCLEAR POWER, OR BEING ACCEPTED INTO THE ENERGY FAMILY

Experience has shown that nuclear energy ideologies can be very beneficial when used carefully, and terribly punishing when used carelessly. Thus, nuclear power can be worth using, but only providing that very capable people are in charge of it.

Work on nuclear technological innovations during the past decade has also shown that significant economic and safety improvements can be made in the hardware, and many are being pursued. However, limitations in the gains which are actually achievable have also become clearer. These primarily concern the contributions to risk due to human errors of all sorts—ranging from those of individuals to those of organizations, common cause failures and external events (e.g., earthquakes). Thus, the future prospect is one for improved, but not perfected, technologies—providing that adequate development resources are applied. Whether they will be provided remains questionable.

Nuclear power technologies have strengths which complement those of other energy technologies. Nuclear power should retain an important role as part of a diverse, robust mix of technological options to be used for future energy supply. The fact that this proposition can be in doubt says more about the nuclear weapons-derived historical context of the nuclear power technology than it does about the hardware or its use to-date.

Nuclear power today is economically important, but not crucially so, as is indicated by the decisions of several countries to live without it. Thus, the question arises of why nuclear power technology is of such great social interest. Part of the answer must be lie the strong emotional response that this technology provokes. With many people this response is one of fear and helplessness, leading to anger and opposition to things nuclear. It has been suggested that an important cause of this reaction to nuclear power arises from its relationship to nuclear weapons (Weart, 1991).

The strength of this response has made opposition to nuclear power a vehicle for drawing attention of other causes which can be linked to it. Thus, we see political pressure groups opposing nuclear power use it as a means of attracting adherents and their funds, as a way of gaining attention, and as an efficient way of claiming legitimacy within a constituency whose ideology at heart is profoundly critical of modern society, particularly of its centralization of political power in the hands of someone else.

Because responsibility for advancing the nuclear power technology and for introducing it into society has largely rested with technocrats these aspects of the debate over the proper role of nuclear power have not often been addressed explicitly by those in charge of it. Technocrats—at least in the United States—are not usually prepared educationally or culturally to define or solve problems having a large social component. When nuclear power has been criticized in technological terms its advocates have usually accepted these terms of debate and have responded directly. Not surprisingly, in retrospect, their responses have typically been insufficient to satisfy their critics, perhaps because they were addressing the wrong questions.

By accepting the battle ground offered by their political opponents, nuclear technologists have ensured that they would be offering arguments irrelevant to the strongest motivations for opposing the technology which they were and are trying to promote. The nuclear power debate has been much more about trust, political enpowerment, and the distress of being helpless in the face of possible annihilation than it has ever been about hardware. If those who would advocate a continuing role for nuclear energy technology wish to become more successful it would be useful for them to redefine the problem which they are attempting to solve and to help their opponents to come to trust them..

For the success of nuclear power it is necessary to engage its opponents terms of fundamental mutual interests, and seek accords which satisfy all concerned. If doing this were easy or straightforward it would not be necessary to hold a gathering at MIT to discuss the future of nuclear power. Hopefully the Second MIT International Conference on the Next Generation of Nuclear Power Technology will contribute to better mutual understanding of the fundamental questions affecting that future.

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ATTACHMENT A

Material Excerpted from Schenler and Golay (1992).

The Tables and Figures presented in this Attachment summarize the modeling assumptions and results obtained concerning time scales for consumption of currently identified economical uranium resources should nuclear energy be used vigorously to displace fossil fuel consumption, and thereby to mitigate emission of greenhouse gases. It is seen that burner reactors would consume identified resources within about two decades and breeder reactors would do the same within about one century.

Table 1.2

U.S. NUCLEAR TRAJECTORY ASSUMPTIONS

1. Electricity demand grows by 2.5%/yr, declining to 1%/yr by 2009.
2. Electrical energy efficiency savings grow from 0% in 1990 to 40% in 2010.
3. The electricity demand curve flattens, with base load rising from 60% to 80% of peak load.
4. The fraction of electricity supplied by nuclear power rises from 25% in 1990 to 50% by 2010.

Table 1.3

WORLD NUCLEAR TRAJECTORY ASSUMPTIONS

1. World population is projected to level off at 11 billion by 2040.
2. World electricity consumption per capita is projected to rise from 17% to 60% of U.S. per capita consumption by 2020, and to remain constant thereafter.
3. The fraction of all energy provided by electricity is projected to rise from 25% to 40% by 2040.
4. Electrical energy efficiency, base load fraction, and nuclear electricity fraction follow assumptions 2, 3 and 4 also used for the U.S.

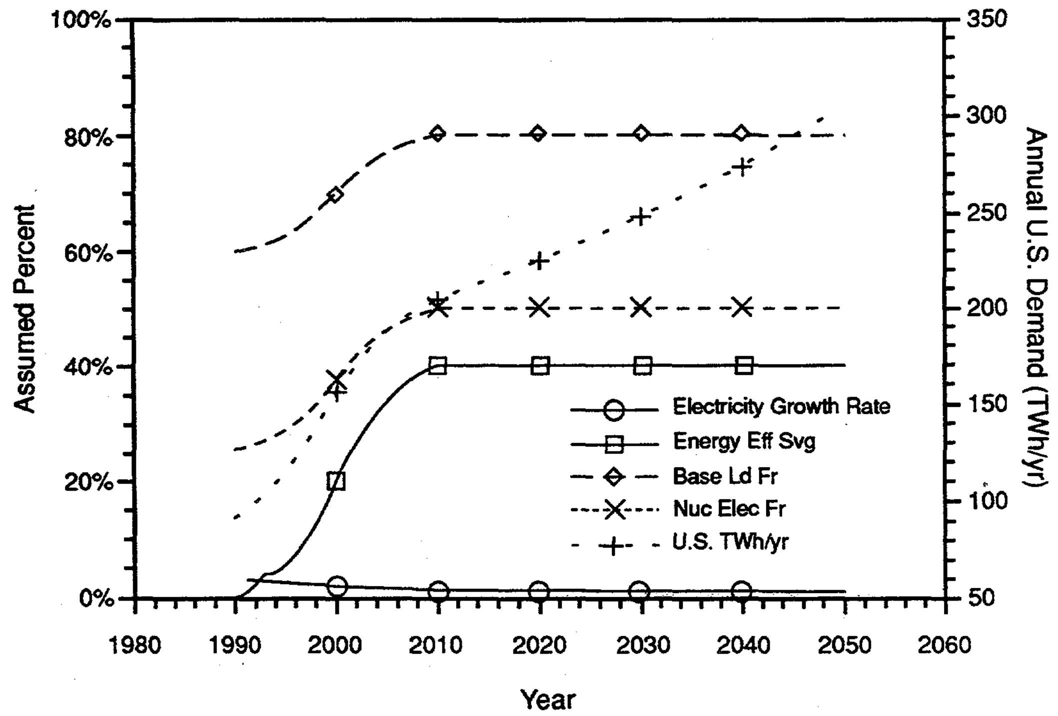

Figure 1.1: U.S. Electrical Demand And Trajectory Assumptions.

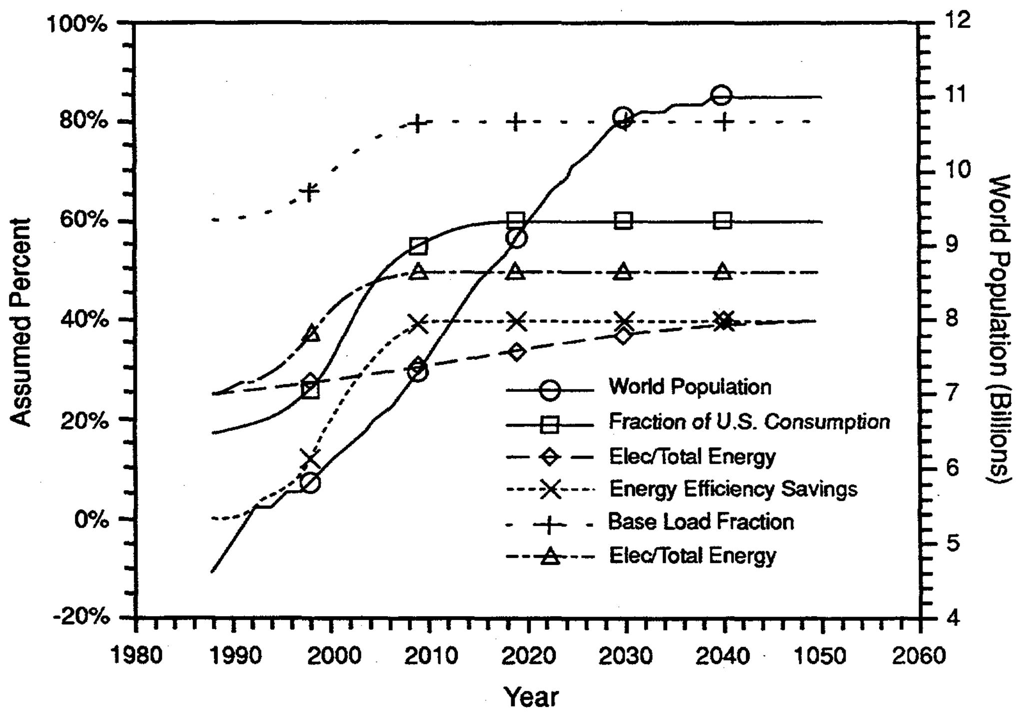

Figure 1.2: World Electrical Demand Assumptions Trajectories.

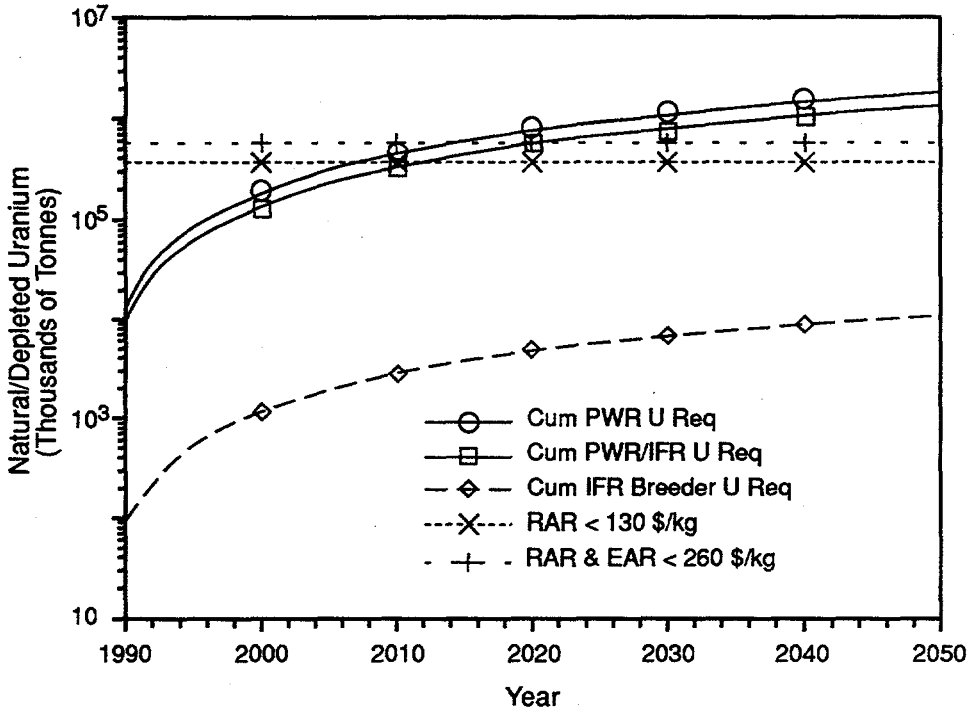

Figure 1.3: U.S. Cumulative Uranium Use And Resources.

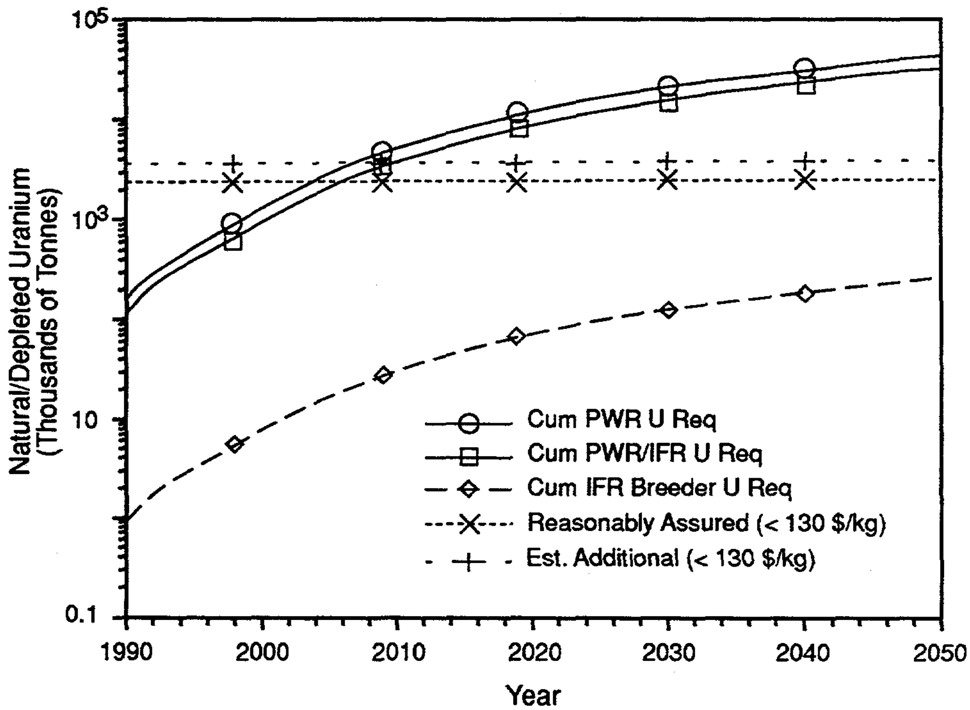

Figure 1.4: World Uranium Use And Resources.

RESPONSE TO M.W. GOLAY

THE WEAPONS SHADOW OVER THE FUTURE OF NUCLEAR POWER

Robert H. Socolow

THE THREE-WAY PREDICAMENT OF THE GLOBAL ENERGY SYSTEM

I share a hope that nuclear power will remain on the list of viable options for the world's future energy system. We live on a small planet that is already asserting environmental constraints on global human activity. I am impressed with the potential for nuclear power to have a lighter impact on our natural environment than a future based on either coal or renewables. But I fear that current trends in nuclear power are headed in the wrong direction.

I frame the future of the global energy system as a three-way predicament:

1. There is enough coal to run the world for several centuries, but that solution has an Achilles heel, the Greenhouse Effect. The plausible outer limits to the disruption of our natural environment that could result from the Greenhouse Effect describe a future where dealing with this disruption becomes the principal task of most of the world's nations.. We cannot in good conscience leave our descendants no other alternative, when there are two alternatives that appear to be promising, if terribly complex and uncertain: renewable energy and nuclear energy. To have a significant impact on the Greenhouse effect, renewable energy must be deployed on hundreds of millions of hectares, and/or thousands of gigawatts of nuclear power must be deployed.

2. The renewable-energy future is of uncertain merit because of its Achilles heel: land-use impacts that are largely unexplored. It makes no sense to "solve" the Greenhouse problem if comparable regional and global environmental disruption can result from the large-scale deployment of renewable energy facilities. The renewable energy research community admits that it has not yet explored deeply the social and ecological implications of deploying renewable energy technology on a very large scale. Some proponents of renewable energy technology are proposing an intriguing finesse: they advocate that the deployment of renewable energy facilities (plantations for biomass, wind farms, fields of photovoltaics) should be coupled with the rehabilitation of degraded lands. From such a vision comes a new research and development agenda for renewable energy—socially responsible and socially responsive.

3. The nuclear energy future is of uncertain merit, because of its Achilles heel, an inevitable coupling between nuclear power and nuclear weapons. It makes no sense to "solve" the Greenhouse problem while creating a world where nuclear weapons are widespread and nuclear war is an acceptable extension of international politics. If the nations on our planet were to pursue an energy system based on fission and fusion nuclear power, on the grounds that it was the environmentally safest strategy to avoid overwhelming the earth's natural systems, only to find this energy system leaking plutonium and nuclear expertise into the military system, leading to bombs that are actually used: what a calamity! The ultimate environmental tragedy is nuclear war. A socially responsible and socially responsive research and development agenda for nuclear power must explore deeply the connections between the military and the civilian atom. (The thrust of this argument is stronger for nuclear fission than for nuclear fusion, but the argument applies to both.)

CONNECTIVITY BETWEEN NUCLEAR POWER AND NUCLEAR WEAPONS

The world, in the past 50 years, has produced almost 400 Gigawatts of nuclear electric power capacity and more than 100,000 nuclear warheads. The public has perceived a single nuclear effort and has concluded that nuclear reactors and bombs come hand in hand.

The public is not wrong here. When you educate a scientist or engineer to become competent in nuclear power, you produce a professional capable of contributing to a program in nuclear weapons. Using Alvin Weinberg's phrase, you have ushered someone into the "nuclear priesthood." There are not two priesthoods. When you create a laboratory (a site of nuclear measurements and nuclear instruments) nominally just for military or just for civilian objectives, you create a capability for becoming engaged with both objectives. The expertise and vocabulary, the instrumentation, many of the institutions, the culture of privileged access to specialized knowledge—all are shared features of the civilian and military nuclear communities. The public perceives a single nuclear elite that does not break ranks. It perceives the wall between civilian and the military nuclear activities (a wall the nuclear community in many countries has been maintaining at great expense) as built on stilts, with the people working at the two activities calling and waving to each other.

That national nuclear power programs are highly likely to encourage national nuclear weapons programs was argued persuasively 25 years ago by my colleague, Harold Feiveson, in his doctoral thesis. He coined the phrase, "latent proliferation," to describe this phenomenon.

Similarly, nuclear weapons determine the fate of nuclear power—in two ways. National decisions to develop nuclear weapons lead to pervasive subsidies of nuclear power, often sufficient to launch its commercialization. But, commercialization is impeded by the ratcheting of public discomfort whenever a nuclear saber is rattled or a nuclear weapon is tested.

The world's nuclear establishment has worked with imagination and determination to minimize the consequences of the connections between nuclear power and nuclear weapons, by restraining leakage in both directions, and much has been accomplished. Most countries have drawn clear physical boundaries between military and civilian nuclear programs. The United States has carefully avoided commingling uranium, plutonium, and radioactive wastes from the military sector with the corresponding materials from the civilian sector. Leakage from the military to the civilian sector has been successfully thwarted by the professional management of nuclear weapons, within a military chain of command presided over by a civilian leadership. The world has been spared, so far, black markets in nuclear weapons, in military plutonium and in military highly enriched uranium. And we have been lucky that no technological breakthroughs in uranium isotope separation have yet brought about dramatic reductions in the cost of highly enriched uranium, so that it has remained in the military sector.

With the objective of thwarting leakage from the civilian to the military sector, while still assisting in the commercialization of nuclear power around the world, the International Atomic Energy Agency has been verifying that civilian nuclear facilities are not contributing weapons material to nuclear weapons programs. The strategy has been moderately successful. In each decade, the world's "club" of nations with nuclear weapons grows only a little larger, and many potential members choose not to try to join. It has helped that nuclear weapons have appeared to the leaderships of many countries to be relatively unusable militarily and politically, reducing internal pressures to build them. On the other hand, leakage from the civilian to the military sector is bound to become more difficult as a result of the determination of several countries, notably Britain, France, and Japan, to commercialize the recycling of civilian plutonium.

NUCLEAR POWER'S FATEFUL CYCLE: SUBSIDY FOR DUAL USE, THEN PUBLIC REJECTION OF DUAL USE

Strategies to reduce accidental and purposeful leakage between military and civilian nuclear programs have not changed a deeper reality of interdependence. Indeed, civilian nuclear power in many countries has been driven along a fateful, slow cycle by this interdependence. The dual-use characteristics of nuclear power drive both its initial appearance in the civilian economy and its later loss of commercial viability. Along the way, public opinion learns to dread nuclear power. This dread surfaces as an upward repricing of the externalities of nuclear power, which raises the costs of power plant operation and waste management well past the point where nuclear power becomes uncompetitive. The dual-use appeal of nuclear power contains the seeds of its own destruction.

In more detail, this is the cycle for a typical country. Initially, nuclear power is quietly promoted by national leaders because of its dual use for civilian and military objectives. Subsidies abound: for R&D, enrichment, waste management, liability reduction. The general public is not initially aroused. Two or three decades later, the country has operational civilian nuclear facilities, and its involvement with nuclear weapons has deepened. Nuclear power subsidies, now too large to be subsumed within government budgets, are shifted to the civilian energy sector. Lost subsidies raise the cost of nuclear power, but not nearly as much as new costs associated with the repricing of externalities that accompanies greater public awareness of the connections between nuclear power and nuclear weapons. Nuclear power becomes subject to the discipline of the market and fails traditional tests of commercial attractiveness. Expectations of nuclear power expansion are abandoned and phase-out begins.

This has been the story in the United States, Britain, and Germany, and it may soon be repeated in Japan. It is likely to be the story, too, throughout South and East Asia, where many countries are now early in the cycle.

The more the public becomes familiar with nuclear power, the higher the implicit price the public imputes to nuclear power's externalities. Nuclear power's association with nuclear weapons creates a deep unspoken disturbance of the soul. Research by psychologists "designed to penetrate the surface veneer of nuclear fear and opposition" uncovers "pervasive qualities of dread, revulsion, and anger—the raw materials of stigmatization and political opposition." Moreover, people carry "shared imagery of nuclear weapons, nuclear power, and nuclear waste" (Slovic, Flynn, and Layman, 1991, pp. 1604, 1605, 1606). "Nuclear Fear" has a long history, explored in an important book with this title by Spencer Weart (Weart, 1988). Dread of nuclear radiation and the endowment of nuclear radiation with supernatural powers are in evidence from the first discoveries by Roentgen and Becquerel at the end of the nineteenth century.

When the public puts a high implicit price on the externalities of nuclear power, it is being highly selective. The externalities associated with medical radiation and with radon in the home are priced much more cheaply. Apparently, a mechanism of selective intensification of Nuclear Fear is operating. In all likelihood, nuclear weapons, exploded over Hiroshima and Nagasaki and threatening the annihilation of other human cultures for fifty years, are the source of this intensification, because the intensification is greatest where the technological culture of a given source of nuclear radiation is perceived to be most similar to the technological culture of nuclear weapons. In dealing with new technology, the public operates with a dread-to-risk factor, a multiplier of the expert-determined risk often not included in formal risk analysis. In the case of nuclear power the dread-to-risk factor dramatically raises the costs of power plant safety and waste management. Conceivably, the dread-to-risk factor could be reduced by changes in the role of nuclear weapons in world affairs.

Some interpret the phenomenon of Nuclear Fear differently. Alvin Weinberg, among others, maintains that the public fears radiation, not nuclear weapons. If reactors and the rest of the fuel cycle can avoid radiation release, the public will calm down. From this judgment comes a focus on technical fixes like "intrinsic safety" in power plant design, and a disbelief in the possibility that the management of nuclear weapons can affect the fate of nuclear power. "Like most nukes," writes Weinberg, "I have always argued that the connection between nuclear power and nuclear weapons was weak" (Weinberg, 1994).

Assertions by leaders of the civilian nuclear industry that nuclear power and nuclear weapons are unconnected have probably been counterproductive. An assertion that nuclear weapons are "not my business" may serve a psychological need for deniability on the part of someone who has devoted his or her professional life to nuclear power. However, making such an assertion, and even more, believing such an assertion, increases the discrepancies between the cognitive landscape of the nuclear power professional and the ordinary person. The nuclear power professional would build greater trust by demonstrating an interest in the links between nuclear power and nuclear weapons.

AN UNTRIED ROUTE TO COMMERCIALLY VIABLE NUCLEAR POWER

There are three possible futures where vigorous nuclear technology endures. A world with abundant nuclear weapons and little nuclear power is one of these futures, not hard to imagine inasmuch as our present world is a close approximation. A second future has both abundant nuclear weapons and abundant nuclear power. I have been arguing here that this second future is intrinsically unstable: nuclear power, after a time, will become uneconomical, as the public superimposes its dread of nuclear weapons onto its perceptions of nuclear power. What the world has not tried to achieve since the 1950s is a third future, a world with abundant nuclear power and without nuclear weapons.

A future without nuclear weapons was in view fifty years ago, at the time of Baruch Plan for the international control of nuclear weapons submitted by the United States to the United Nations. At the time, hardly any of the motivation to internationalize the control of nuclear weapons derived from a desire to make the world safe for nuclear power. It is time to revisit this old thinking. For, only when international political life ceases to be dominated by the threat of nuclear war can nuclear power play an important role in the energy system of the future.

For nuclear power to be compatible with the exigencies of the next fifty years, the world does not need to abolish nuclear weapons instantly. It will be sufficient if nuclear power can be embedded in a new reality, persuasive both to experts and to the public, where, in every region of the world, nuclear war is less likely in the presence of the institutions that govern nuclear power than in their absence. Working out the institutional and technological implications becomes the task at hand for the nuclear professionals.

The Baruch Plan was not implemented. Many would say that its implementation required the fulfillment of naive assumptions about human nature and international politics. Is it truly humanity's destiny to be tribal and violent without limit? If so, then nuclear power will always lead to warfighting with nuclear weapons, and nuclear power should be removed from the list of options for the world's energy system sooner rather than later.

I believe that no one can discern human destiny. As humankind internalizes the new realities of environmental constraints, not only our tribalism but also our sense of shared global responsibility will increase. Who is to say which effect will be more important?

COMMERCIAL NUCLEAR POWER IN SUPPORT OF A NON-PROLIFERATION REGIME

This is one world in terms of technology, politics, economics, and the environment. What happens in one country affects what happens in another. As regards nuclear power, this is much more than a cliché. Nuclear power demonstrates a unique financial interdependence and an important political interdependence.

The financial interdependence is vivid: a reactor shutdown or radiation release in one country affects the operability of the nuclear power plants in every country. Every nuclear power plant is hostage to every other one. The hazardous conditions of operation at the power plants in Eastern Europe, for example, have portentous implications for the operability of nuclear power plants in the United States.

The political interdependence is a special case of a more general observation: <u>Over the long term, no technology of importance in one country can be effectively denied to another</u>. In particular, no one can force a different course for Northern technology and Southern technology. Specifically, the future of nuclear power lies either in both the North and the South or in neither (Feiveson and Goldemberg, 1980).

Some Northern proponents of nuclear fission power have expressed a preference for a world in which not all countries have access to nuclear fission reactors, on grounds of safety of operations and proliferation risk. Colonialism is very much alive in such thinking. Given the destructive power of resentment, moreover, such thinking is counterproductive. The nuclear power system must be designed so that it is robust against inept operation, a risk no culture has the power to eliminate. And the nuclear power system must embed "proliferation resistance" in system design (Williams and Feiveson, 1990).

With the end of the Cold War, nuclear weapons are being evaluated afresh in every country, and nuclear weapons proliferation is receiving unprecedented attention by the world's political leadership. Of particular importance are the judgments in the process of being formed throughout South and East Asia. Possible outcomes of this evaluation range from, at one extreme, a universal judgment that nuclear weapons are what every country aspiring to regional leadership must deploy, to, at the other extreme, a universal taboo of the kind that now adheres to biological weapons.

Just at a moment in history when a taboo might conceivably be established, the global nuclear power community is not being helpful. Western Europe and Japan have aimed the world 180 degrees away from the path to a proliferation-resistant nuclear economy, by plunging the world headlong into a "plutonium economy." France, Britain, and Japan are greatly expanding their commercial reprocessing facilities, where plutonium is separated from spent fuel. The resultant stockpiles of separated plutonium are motivating the production, transport, and use of "mixed oxide" reactor fuel containing plutonium. In the next few years, unless major reversals of policy in several nations occur, the plutonium route to nuclear weapons will become qualitatively easier, as existing international institutions designed to prevent leakage of civilian plutonium into the military domain, like the International Atomic Energy Agency, are overwhelmed. The global civilian nuclear industry appears to be risking a devastating incident based on an actual plutonium diversion or even a bluff about a plutonium diversion, an incident that would surprise and alarm the public in a new way and would put one more arrow in the heart of civilian nuclear power.

The global nuclear power community continues to exaggerate the gap between nuclear power and nuclear weapons. It fails to confront the fact that the plutonium in the spent fuel from civilian power plants is weapons-usable. It fails to abandon the reprocessing of spent fuel even after its original rationale—the urgency of the breeder—is gone, and only unjustifiable economics remains. It fails to make proliferation-resistance in the management of the nuclear fuel cycle a central design criterion: nuclear fuel cycles based on thorium would have received much greater attention over the past 50 years, for example, if proliferation resistance had been higher on the list of design criteria. It fails to confront the linkage between the surging commitments to nuclear reactors in South and East Asia and the dual-use characteristics of the system in which they are embedded. When the global nuclear power community believes its own myths, it loses the sharp edge of reason and forfeits much of its claim to leadership.

NOW IS THE TIME FOR NUCLEAR POWER'S U.S. LEADERS TO BECOME ENGAGED IN NUCLEAR DISARMAMENT

What if the leaders of the U.S. nuclear power establishment were to request and accept an important role in moving the world toward nuclear disarmament? Leaders from the electric utility industry, the vendor corporations, the intervenor institutions, and both the fission and fusion research communities would become outspoken advocates of no further tests of nuclear weapons, no further production of fissile materials, and other global policies that reduce the danger of nuclear weapons. They would make their positions known through Congressional hearings, at press conferences of the American Nuclear Society, in op eds, and through professional societies. They would use their influence world-wide.

As one specific example, they would invent ways to share in the management of the institutions now being designed for the management of military uranium and plutonium. Management challenges include storing and denaturing the uranium and plutonium retrieved from the nuclear weapons currently being retired via the START agreements.

Any bold initiative on the part of the civilian nuclear leadership that acknowledges the linkages between civilian and military nuclear activities would have a good chance of altering public perceptions of civilian nuclear power. Nuclear energy, fission and fusion, badly needs a positive surprise. The public would be surprised, were the leaders of civilian nuclear energy to do something dramatic and, to the public, out of character and deviating from expectations. From such cognitive dissonance, sometimes deep change occurs.

For the civilian nuclear leadership the timing is auspicious. Only a few years ago an outspoken role for the civilian nuclear industry on behalf of nuclear disarmament would have been politically impossible. Recent events, including the discovery of clandestine nuclear facilities in Iraq and the disruptions of authority in Ukraine and Russia, make it politically safe to promote the proposition that nuclear weapons are no longer a good foundation for the security of any country, including the United States. The leaderships in most countries regard nuclear weapons as less usable and less valuable than they did, say, five years ago. The U.S. nuclear energy community should be emboldened by these shifts in attitudes about nuclear weapons.

CONCLUSIONS

As an environmentalist, I hope that the nuclear option can remain available throughout the next fifty years, as the magnitude of the environmental challenge becomes better understood. The nearly universal adoption of the American lifestyle as the objective of global industrialization guarantees that we will rapidly enter an era of dramatic physical and biological transformations of our small planet. To the extent that nuclear power can grow to become an important component of the global energy system, these transformations will occur more slowly. But nuclear power will not grow until the public's assessments of risks more closely resemble the expert's assessments. And that will only happen when the public becomes convinced that nuclear weapons are not a danger to the world. The prospects for nuclear power are brighter, the more successful the move toward nuclear disarmament.

The nuclear power community could help its own cause by becoming actively involved in persuading the world's nations to end their reliance on nuclear weapons for national security. This is not an unthinkable proposition at the end of the Cold War. It is possible to say "yes," nuclear weapons were needed for the first fifty years of the Nuclear Age. They have served their purpose. They kept the peace. Over the next few decades, they can be thanked and retired.

The nuclear power community knows, more than any other group, how to move along this road: how to close down and monitor military nuclear facilities; how to sequester plutonium in relatively unusable forms; how to denature weapons-grade uranium; how to redeploy nuclear scientists on behalf of tasks within civilian nuclear power that are badly understaffed today, such as waste management and the decommissioning of facilities; how to devise, implement, and monitor a new class of arms control agreements that address weapons materials.

Above all, the nuclear power community has the leverage to change the culture of the broader nuclear community, so that it becomes universally understood, both in that community and by the public, that nuclear weapons development anywhere in the world endangers the prospects for nuclear power everywhere in the world.

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WHAT ROLE SHOULD NUCLEAR POWER PLAY, AND WHAT WOULD LIFE BE WITHOUT IT?

DISCUSSION

U.S. Energy Researcher:

I think that a fundamental premise that Prof. Golay has raised, if true, dooms the nuclear enterprise. He premised that the possibility for having a future for nuclear power rests upon the notion that there should not be any more serious accidents; that a large accident would be a serious setback. However, I am sure that large accidents are going to happen. Sooner or later, in the Eastern European block of countries, we will be seeing one. Maybe it will not be of the Chernobyl size, such an accident is very unusual, but rather of the Three Mile Island (TMI) size. The likelihood, of a TMI-size event that would destroy the reactor is very high in most of the nuclear reactors in the eastern countries, very high, unacceptably high, incredibly high! The results of risk assessments show that for a lot of nuclear reactors the probabilities of core damage are around 10^{-3} per reactor year, or even as high as 10^{-2} per reactor year.

Those reactors at 10^{-2} per reactor year are unacceptably risky. However, they are operating daily. An effort to try to fix them is underway, but it is unacceptably slow, and perhaps will not be successful. Therefore, it is my prediction that a bad accident will happen.

Everybody in this room needs to face the fact that risks of accidents are high. Now there are those who say it is acceptable to have a little TMI accident in Bulgaria. That it is not going to affect the world. Maybe we can assume that this is true. It is my view that operating these reactors unsafely necessarily leads to doom. This is because I do not believe that we can enforce safe operations on those Eastern block countries.

Prof. Michael Golay (MIT):

I think that it is very important for us to avoid another accident. However, I would not conclude that the nuclear enterprise will end, should another serious accident occur.

U.S. Energy Researcher:

I did not mean to conclude that either. I was just very pessimistic about your premise. I believe that the premise is therefore incorrect. I think that the nuclear enterprise will survive another accident just as it survived Chernobyl, but an accident will sure make doing so harder.

U.S. Power Industry Professional:

I recently spent a week in India, and came face to face with the desperate need for energy. In this case water was needed. However, you do not get fresh water without energy. This is also true of many places in the world. I disagree with Prof. Golay regarding the proximity in time of having advanced forms of nuclear power by perhaps by 2020, or of developing nuclear technologies adaptable to China or India or a number of other countries. As the preceding speaker has mentioned there are many potential problems which can arise between now and then.

The problem with the technologies that Prof. Golay talks about, in terms of goals and capabilities which would permit them to be put to use now is that they do not exist. They do not exist in terms of true prototypes. They do exist in terms of desires. We have noted the characteristics needed to provide a serious response to global warming. We must talk about the limitations of uranium supply. We do have reactors concepts that could be finished in less than a decade that would be 50% more early efficient, which means being 100% less polluting, 50% less waste producing. I think such a reactor could be very significant in a world that needs these kinds of technologies now.

U.S. Energy Researcher:

I would like to mention something about uranium resources. My colleagues and I recently estimated the implications of uranium resources. In doing this we talked to a lot of people in the geological community. If you talk to economic mining experts you find out they are not very frightened about trends concerning mineral resource availability in general. It is noteworthy that perhaps half the geologists in this country would say that we are not going to run out of uranium for the next hundred or two hundred years, even should we have five thousand reactors. Their rationale is that if you examine the histories of copper, nickel, zinc in terms of demand growth rates for those materials, they have been increasing by three to five percent a year for a couple of centuries. The prices, when adjusted for inflation, for all of these minerals have not gone up. They have stayed just about the same.

What has been happening is technological innovation. The mind has compensated for lower ore concentrations. There are many people in my community who would say that uranium would be likely to do the same. This expectation is based upon experience. However, we have no guarantee it really will do this. I question whether we will run out of cheap uranium in the 20^{th} century or the 21^{st} century. It is not sure bet at all that we will.

Academic Socio-Technological Scholar:

I first got involved in nuclear energy about 20 years ago at just about the time of the first energy crisis. I am struck by how many familiar faces are here from 20 years ago. However, I also see so many familiar issues from 20 years ago. I note that two very notable reactor accidents have happened since that time; one in TMI and a serious one in Chernobyl. Also, reprocessing has been on and off, plutonium use has been on and off. Many problems are exactly in the same state as they were 20 years ago.

However, during all that time the terms of the debates have not changed enough. This is something which I characterize as a "little black coat button syndrome." I noted way back in the 1970s that I had a little black button of nuclear fuel from the Department of Energy. It represented my nuclear energy consumption value of a year's accumulated associated radwaste. That button, of course, was simulated. But also, what was not given to me was the amount of land area that would have been associated with that button had it been genuine, and the amount of other resources that would have been associated with my year's consumption of nuclear energy. Prof. Socolow raised this point and I want to emphasize it. Among the issues which we need to talk about are some which were not perceived at all in 1973. Then, people were not thinking of nuclear energy as something which was to be deployed in really large scale other than in terms of reactors. They also would not be spending two whole days thinking again about the reactors, and just about the reactors, while forgetting everything else that goes along with making them possible.

Really small power plant sites, like European sites, produce just as much as 250 watts per m^2 if you include the mining, the milling, the transportation, the waste disposal and the amount of floor area devoted to regulatory practices. Because the reactor core has such a high power density, nuclear engineers typically think about the core first, because it is very high powered and a very intense source of energy. However, in some ways this picture is not exactly correct. I also would include in our understanding such things as human floor area or social floor area occupied when we compare nuclear energy to other alternatives.

I think there need to be some other kinds of conceptual thinking about what a deployed nuclear system means. Besides, this we must consider the alternatives before deciding what systems to use. It may be that the alternative is a less efficient, more dispersed, more resource-consuming source than the nuclear one would be. In fact, it may not be that the differences among energy alternatives are so large. If one has to make the argument that you have to accept certain costs in order to get certain benefits, one needs a more integrated and holistic view of what constitutes the costed benefits other than reactor accidents or other point-events like that. In fact, the distributed cost is not well integrated. It might be good to talk about these things. I think that this was basically the previous speaker's point.

Public Policy Analyst:

I would like to introduce the idea that the electric utilities will not be the ones making technology choices in the coming years. As we have already seen in the United States, and as I believe as will spread throughout the world, the market for power generation will become less and less a monopolistic market in which the electric utilities will be making decisions on behalf of their customer and will be the primary designers and constructors of power plants. Instead, I think that many observers would agree that the electricity market is moving to being a real market for power providers. We shall see third party providers offering power to utilities, third party providers offering power to end-users, and end-users providing their own power to themselves and other end-users. In that kind of a market what will drive decisions regarding new energy sources is an environmental rubric as established by national legislators. This will influence businesses using the traditional risk and return decisions that are faced in other markets.

I think that one of the things that will be worthwhile discussing over the next couple of days is the question of whether nuclear power can satisfy an attractive risk return relationship when corporations are making choices about forms of electric energy production for their own use or for sale to utilities or to other parties. I think, also, it is important to recognize that in a true market it will be very unusual to pose decisions in terms of a single unit 800-900 or 1000 MW power plant. Chances are that the units will be in sizes ranging from 50-390 MW. You might have 690 MW power plants that will be built in increments of 150-250-300 MW units. A question for this Conference is whether that kind of market is achievable by the nuclear power industry.

U.S. Energy Researcher:

Basically, what I would like to address is to expand on Prof. Golay's and the first speaker's remarks and question on Chernobyl. I spent a year and a half living in the town of Chernobyl, conducting my doctoral dissertation research there. I am intimately familiar with both the design of RBMK, the Ukraine's and actually the whole CIS's situation regarding nuclear power. Being in Chernobyl has given me a unique perspective on how that side views western perceptions about their nuclear power industry. I quote a Greenpeace activist in Ukraine saying that: "Chernobyl is Ukraine's ecological tragedy and 2% of nuclear energy that Chernobyl supplies to Ukraine citizens will never justify Chernobyl's victims of the past present or future." Now, putting the nervous language aside, I would like to first of all note that Chernobyl station does not provide 2% but rather 16.1 plus % of Ukraine's nuclear energy. Thus, I feel that this is an irresponsible statement from Greenpeace. Secondly, even if you include all of Ukraine's energy production, electric energy production, that means hydro and the various fossil plants you see that Chernobyl supplies 5.6% of its energy. Now for a country that is bigger than France and having a population of 52 million. I am sure that shutting down the Chernobyl station will be a problem for Ukraine.

I must urge the audience not to paint Ukraine's position as a black and white one. Ukraine is in a very difficult position vis-a-vis Russia and its own problems. I would like to see us respond quickly to help them. I feel that Chernobyl stations continued production of electricity is a bad decision. You do not need Chernobyl accidents to prove this. It has been known for 14 years, the British were the first to point out the fact that the plant has a dangerous design.

I have had "carte blanche" access to the Chernobyl units, operating units one and three, and unit two, along with the sarcophagus and units 5 and 6. I have to tell you that the safety culture there is something on the order of horrifying. Mostly that has to do with the baggage that Ukraine has carried with itself from the Chernobyl accident.

The other point that I would like to make is that the Ukrainian argument of needing energy independence from Russia is fundamentally flawed. I feel that it is desirable for Ukraine to be independent from Russia in all aspects. But, the reason why the energy independence argument is flawed is that Russia is the only country that produces and is developing the RBMK reactor. If Ukraine wants to become independent from Russia in terms of energy, it should then be eliminating use of the RBMK because all of the specialists and all of the fuel fabrication facilities are located in Russia and not in Ukraine.

The other side of the coin for that argument is that the rest of the reactors in Ukraine are VVERs which are more or less equivalent to the PWR. Ukraine could look to the west for help given that it is a PWR. Also, Ukraine's minister of energy and electrification has said that, Ukraine's shortage of energy has to be qualified by the fact that it has a lot of chances to reduce energy demand, especially given the fact that the economy is falling. Ukraine is strangled by the loss of Russia's fuel.

The last thing that I want to say is that the reason why Ukraine is in a difficult position is that Ukraine has very little expertise in the RBMK. They need to decommission the entire Chernobyl plant. I do not think I need to tell anyone here how difficult a task it is to decommission a reactor, given that there are operating reactors right next to it.

U.S. Government Employee:

I want to thank Prof. Golay for putting on this Conference, and convincing the DOE to support it. I look forward to many discussions during the public and private times. However, at this Conference I was puzzled because of the order in which the factors affecting nuclear power where stated in Prof. Golay's talk. My experience, not based upon scientific evidence, is that the most important thing in the public's mind concerning nuclear power is nuclear waste. It is the first question which one is asked when one talks about nuclear power. I would place it on top of the list by far.

The item which needs to be resolved by the nuclear energy community (by that I mean the government first and the rest of the nuclear industry as well) is that of wastes. The question for this Conference to debate is not that of nuclear power. The proper question is that of what we should do to generate power, electricity. Technologies to do this include nuclear, most probably fossil fueled, and possibly over the long term some renewable ones in some proportion. Also, addressing the comparative risks to society of different technologies is extremely important here. The last time that this was done was in a Ford Foundation study in the 1970s which was published during the Carter administration. At that time it was made clear that mining of coal had killed a hundred thousand people in this country. I think that we need to look not just at the effects of fossil fuels upon global warming, but we need to look at the effects of the use of fossil fuels upon public safety. We should keep this in mind when we are talking about Chernobyl accidents or TMI accidents or 10^{-5} or 10^{-6} per reactor year core damage probabilities.

Public Policy Analyst:

I will not respond to the question about the accuracy of Greenpeace statistics in Ukraine except to say that in the minds of my colleagues and myself nothing could justify any operation under the current conditions at Chernobyl. In my mind this is the worst thing that has happened in human history. If for no other reason than that of the Chernobyl example, we are determined to end the experiment with nuclear power. I believe that basically time is on our side, and the end is more imminent than the nuclear industry may believe.

I will agree with most of, or everything, that has been said in this meeting, so far. Actually I am surprised at that, being from Greenpeace. The reality is that there are a lot more burdens to nuclear energy even in the present and the future than those of weapons and waste. However, these are very major considerations. We also have to consider the fact that people who live in the area near the nuclear plants are very concerned about emissions from them, which they and I believe, rightly so, cause cancer. They still also have the evacuation issue which has not been addressed, and you also have the possibility of accidents such as we have seen at Chernobyl. There are also people, including myself, who believe that people were killed in the TMI accident.

In addition to that I think you have an overall power and aura caused by the fact that this technology was never agreed to in a democratic frame of mind by the American public as a whole and specifically, and more importantly by the people who live near the reactors. Until you can get a consensus from people who live near these reactors, which I believe frankly you will never get, the industry is doomed. This is particularly the case concerning the idea of trying to build new plants in this country.

You may have more success in the Third World. I think there are problems there also, not the least of which is the possibility an accident. I think that in addition to all of those burdens the number one burden that this generation and the next generation of nuclear power plants face is that of the poor economics. We have estimated that $500 billion have been put into the commercial nuclear power experiment. That estimate was made by our energy associates over two years. You may dispute the result by 10 or 15% on either side, but that is our basic estimate. For $500 billion we have gotten 20% or so of our electricity, or less than 10% of our total energy.

I think, in general, from the perspective of our concern for serving the general public, that this has not been a good investment. To continue with this mode of technology for a new generation this industry is going to have to do a lot better than to provide good economics and economic viability. I do not think that the needed performance will be obtained. The reason is basically that renewable energy technologies and efficiency improvements are a lot further advanced than, I think, the nuclear industry is willing to admit.

If land use is the "Achilles' heel" of solar power then basically there is no "Achilles' heel" if you look at the windmills, of which there are 15,500 now operating profitably in California. We are obtaining five cents to three cents per kW/hr with windmills. Also, livestock can graze at the base of the windmill tower. Agriculture can be performed at the base of the tower, and the agricultural community is very enthusiastic in general about windmills because of the increased income obtained from the lease of the land.

Future photovoltaic arrays will be sited on roof tops in this country in the next century. Solar energy is doing fine in the desert. Biomass is very popular and gaining increasing popularity in rural areas. The land use intensity issue is a red herring that does not exist.

The reality is that given all the other results concerning nuclear power, present and future, from weapons, waste, emissions and evacuation, ultimately it has been a bad economic bargain. I do not think that this technology has an economic future. Six reactors, as you know, have been shut in the last few years and economics has played a major role in that result. I can name a dozen more reactors with likely prospects for shut down within the next couple of years, based upon a range of issues. That is basically it. I think that the industry was sold to the public as being too cheap to meter. You may regret that phrase, but that is the phrase that the industry is stuck with. What has changed? For over 20 years for us, we have been hearing about the same issues from the nuclear side, but for us the technologies that we are arguing for in the abstract are improving. If only the Federal research money would go to solar, then we would be competitive. The reality is that the technologies that the antinuclear movement was arguing for 20 years ago are here now, and are moving nuclear power to the margin. They will be at the center with nuclear at the margin in the future.

Academic Socio-Technological Scholar:

I teach comparative development to graduate students many of whom are from China, Japan, India and Pakistan. They are very interested in nuclear technology for both weapons and the energy supply reasons. They look at the comparative risks, particularly my foreign students, very differently from the way discussed so far this morning. They see nuclear technology as a question of balancing the risks of poverty and starvation; particularly in India, Pakistan, China and Iran, versus environmental concerns and severe health risks. This is true particularly in China due to fossil fuel burning.

They are concerned about the risks of facing a nuclear armed-opponent without the benefit of having access to nuclear arms or assurance of an American nuclear umbrella. They risk starvation due to lack of sufficient energy. One quarter of the inputs to agricultural development are energy inputs. The years of working lives lost as a result of lung disease or fossil fuel burning there are balanced against the risks of failed nuclear deterrents and nuclear war. They are regarded very differently in the United States from let us say India, Pakistan, China , Iran or Iraq. We balance these risks quite differently from these large countries that are newly industrialized and still developing.

They are probably the largest market for the American nuclear power industry for the next 20 to 30 years. For those well intentioned "folks" who say that perhaps nuclear energy does not provide a competitive return on investment compared with renewable sources, I will argue that it is very hard to defend oneself against the nuclear armed aggressive neighbor with solar energy or hydroelectric energy, and that this factor plays a major role. It is precisely the dual use potential of nuclear energy for peace or war that is important. For peaceful development or for military uses that duality drives the predominant part of the potential world market. There are nuclear power development and nuclear arms races incipient between China, Japan and the Koreas. Also, Pakistan and India, where there was almost a nuclear exchange a few years ago, and Iran and Iraq are possibly other places for nuclear arms races.

Consider the expanding applications of nuclear energy worldwide, in the most rapidly growing areas both economically and in terms of population. We must consider the case for developing proliferation-resistant nuclear power plants in preference to those advancing safety and economic performance. We all know that the World Bank and the Agency for International Development (AID) frown upon the development of or investment in nuclear power in developing countries. This is because, as Prof. Golay has pointed out, they may not be sufficiently proficient to handle it safely. This fact has not stopped them from developing and maintaining their own national airlines. It is also very unlikely to stop them from getting nuclear energy for both peaceful and military purposes. These countries constitute the most rapidly growing nuclear market worldwide. We can try to modify that market by developing more proliferation resistant reactor designs, if that is possible; or we can continue to look at things from our own perspective and optimize the designs according to selection criteria suited to Western Europe, and North America. In doing this we can miss the opportunity to address this much larger and strategically more significant market in a way that works well for its arms control and reduction of nuclear weapons inventories.

Academic Socio-Technological Scholar:

I wish to request an elaboration from Prof. Golay. Most of his remarks, I believe would be found to be reasonable by the so-called critical elite, with one exception. I was puzzled by this exception. I am asking him why he says that it is necessary for nuclear energy to be deployed in different countries in parallel and at "industrial strength."

I gather he means by that to concentrate hardware on a large scale. I assume he is referring to a management which is hierarchically structured. I will suggest that in the last two or three decades, there has been a historical trend that has been approved among the critical elite that opposes hierarchical management, and speaks for the use of layered management; which opposes concentrated hardware and favors distributed hardware.

I refer to the trends in manufacturing in Japan and in Italy. Also, computer laboratories are now dispersed, and the hardware tends to be distributed also. So, I am asking why he calls for this requirement in the deployment of nuclear power. It is not simply an economic investment, it is also a political and ideological question.

Prof. Golay:

My comment had to do with the potential nuclear power response to global warming, where the requirements for a vastly increased scale of energy production from nuclear would be implied. Concentrated technological organization is not a necessity. Rather, I think that the economies of scale will continue to rule, which will favor concentration. This will be true regardless of whether you go to a large scale activity for either technological or energy production. We may attempt to reduce capital costs for example, through modularization, standardization, and factory fabrication of units, these are all tactics which would improve the economics of small nuclear power plants. I think that the overall management of whatever nuclear technology is deployed will still give an advantage to centralized control and industrial concentration. I understand how one can disagree with this view. It is simply my guess that this is the way that things will work out, which is not to say that this is the only possible way.

International Energy Researcher:

I think that Prof. Golay has touched upon most of the main issues in the nuclear debate, but in my opinion, at least, not all of the issues have the same importance. Their importance is related to the nuclear power role and the renewable energy sources role. I think that they have to be considered as the current [Italian] Minister of Research in my country has said: "They are different arrows for energy role aimed to different targets." So, we have to consider all of the potential energy scenarios, and address the uses of one or the other of these energy sources in their eligible roles.

As regards the other items touched by Prof. Golay, I admit that my opinion might be biased by the current situation of nuclear energy in Italy. But, I think that the most important problem for nuclear power is gaining and maintaining public acceptance. Included in this is also acceptance of a realistic risk evaluation, including a comparison among the different type of energy sources. Also, we must consider the minimum dose and risks below which accident effects may be ignored.

The other highly important issue is that of finding a real solution to nuclear wastes. We have really several solutions for this problem, but I think that they need to be accepted by all our opponents. Then, we have the duty to choose a real solution that is of unquestionable reliability. At that point, in order of importance, comes economics.

I am not, thus far, so deeply concerned about that the problem of nuclear weapons proliferation. We have the duty, in my opinion, to avoid confusing safety passivity in nuclear power use, with weapons technology. Especially, we must do this when this confusion is made by the opponents of nuclear energy, as often happens. I am here in the country that initially developed nuclear weapons, and I came from the country where Enerico Fermi was born. In a way I feel that nuclear weapons are a reality and that they have given us the longest period of peace in, at least, European history, more than fifty years until now. We have to live with this situation, and also to try to correct this situation by destroying many of the warheads by using the same technologies that gave them to us.

U.S. Energy Researcher:

In the First MIT International Conference on the Next Generation of Nuclear Power Technology, there was mention of a time horizon for reactor technology development of around the year 2050. In the opening address of this Conference, Prof. Golay stated the year 2020 for the evolutionary technologies, but for the liquid metal reactor, did not even offer a date. What I would like to suggest is that the need for the liquid metal, fast neutron reactors are more eminent or urgent than this treatment would suggest. I would like to give some reasons for why I think that is the case.

However, before I start I would like to note that the term of fast breeding is a misnomer. It is a misnomer in a sense that it has nothing to do with how fast we breed. It has nothing to do with uranium resource availability, or with the total value of resources. There are more than enough existing resources.

We have about 700 tons of plutonium contained in commercial nuclear spent fuel today. Even if we do not add any more nuclear generating capacity by the year 2010, we will then have more than 2000 tons of plutonium. Even disregarding uranium resources, just in order to utilize the existing plutonium inventory in spent fuel, it will be necessary to build more than 100 GW of liquid metal reactors. They will generate energy for a long time.

However, there are more immediate concerns that we have to deal with. Some have already been mentioned: waste management, or weapons proliferation concerns; safety. These are all the basic problems that liquid metal reactors (LMRs) can address. The LMR can provide some technical advances in dealing with waste management. This is a very profound and immediate promise of this reactor concept.

I also agree to some extent with Prof. Socolow that we may have built the wall between nuclear weapons and nuclear power too high, especially after the cold war. We have to deal with what to do with the weapons stockpile of plutonium, as well as to harness uranium. We have to deal with proliferation. While there are temporary solutions such as the advanced reactor technologies, the liquid metal reactors are addressing revolutionary changes in nuclear technology.

We need to stand back and have a critical view of the nuclear problems. The timing in seeking solutions maybe too urgent. If you look at all other technologies they are making continuous improvements. But instead, what have we done in the nuclear field? It is true that we have to keep the existing reactors reliably, safely operated, but we must not be distracted by the existing reactors. In order to have a future in the nuclear field why not take the opportunities provided by advanced reactors and find revolutionary improvements in problem areas: safety, waste management, proliferation resistance. I think that the more that we feel that these problems are urgent, and we develop those technologies, we will assure the future for nuclear power. I think that the nuclear community has to focus on developing the technology, demonstrating the value of advanced technology and to come out with a strategy for long-term nuclear development.

SESSION TWO

HOW LONG WILL THE CURRENT NUCLEAR POWER REACTORS OPERATE?

Andrew C. Kadak

Yankee Atomic Electric Co.

RESPONSE:

Mason Willrich

Pacific Gas and Electric Enterprises

INTRODUCTION

Session 2 – How Long Will the Current Nuclear Power Reactors Operate?

The purpose of this session is to focus upon the conditions of the operating nuclear power plants, to examine their state of health and to discuss the associated implications for the future of nuclear power. This examination is necessary because some plants have been shutdown prematurely, and the remaining plants are under unprecedented competitive stresses. It cannot be taken for granted that they will be able to operate to the end of their useful lives.

This situation is exacerbated by uncertainties in the electric utility decision-making climate created by the unpredictability of the actions of the safety and economic regulatory authorities (respectively, the Nuclear Regulatory Commission (NRC) and the Public Utility Commissions (PUC)). The net effect of such uncertainties is to inhibit utilities from making investments which would improve operational performance. The utilities hold back because they are not sufficiently confident that such investments can be recovered in future revenues.

With the NRC new factors of uncertainty continually arise as new regulatory policy issues are addressed. Important current examples include the treatments of plant aging and of licensed operational life extension. In addition to procedural uncertainties the PUC processes exacerbate uncertainties because they are highly politicized, with energy and environmental pressure groups influencing these agencies in order to advance their particular agendas.

As with other industries, the nuclear power industry is a positive feedback system. The result of premature plant retirements is to weaken the positions of the surviving plants and to diminish the prospects for the future of nuclear power. This occurs because the strength of the industry's infrastructure depends upon the number of plants which they serve. As this population decreases the number of firms and universities involved with nuclear power also decreases, as has been happening over the past decade. These effects then feed-back to make continued operation of the surviving plants more expensive, which in-turn weakens the infrastructure further.

These interactions are important for the future of nuclear power because the capability to innovate and to attract highly capable people to work in nuclear power depends upon the prosperity of the industry, particularly as nuclear applications, broadly defined, become less of a governmental activity. Because the nuclear power industry is under considerable stress, it cannot be taken for granted that conditions which would favor success will obtain.

HOW LONG WILL THE CURRENT NUCLEAR POWER REACTORS OPERATE?

Andrew C. Kadak

I have been asked to address a generic question, "How long will the current nuclear power reactors operate?" This question unfortunately does not have a generic answer. The answer is very plant specific. Even on a plant specific basis, the answer is very complex, incorporating economics, public acceptance, need for power, regulatory climate, and politics among some of the factors. Interestingly enough, I have not been asked the question, "How long can current nuclear power reactors operate?" This question has a technical answer that may be generically applied.

As most of you know, Yankee Atomic Electric Company was a lead plant for license renewal that would have, if successful, extended Yankee's licensed life by another twenty years for a total of sixty operating years. As you also know, Yankee chose, for economic reasons and for reasons of regulatory uncertainty, to shut down its plant on February 26, 1992. As one of the industry pilot plants for license renewal, we are convinced that, technically, nuclear plants can be operated for sixty to seventy years safely and economically.

As a company that chose to shut down its only operating asset, it is also quite clear to us that the economics of continued operation for plants in their later years will depend on the ability to renew licenses. In our case, the unknown condition of the reactor vessel; a regulatory process that was unable or unwilling to identify clear and concise acceptance criteria for restart; at a time when the demand for electricity was low due to the recession; and a remaining license life of only eight years; our decision was to shut down the plant. The decision to shut down the Yankee plant and not continue to struggle with the regulator at a time of excess power and with the economic evaluations demonstrating that consumers could save over $100 million in net present value dollars by shutting down rather than operating the plant was relatively straight-forward. Thus, I stand before you able to speak with some experience on both the "can," defined as the ability of nuclear plants to run beyond their licensed life, and the "will," defined as the economic reality of being able to so. Answering the question, "How long will current nuclear power reactors operate?" is not easy, but when faced with a plant specific decision, the question is answerable.

My generic assessment is that most nuclear power plants can and will operate to the end of their initial operating license of forty years. The determination as to whether they do depends on economics and politics; namely, whether the plant is producing competitively priced electricity in a political environment that supports its operation. The continued operation of existing nuclear plants depends on the financial regulators, be they on the state or federal level. If they support, either by their policies or their specific rate treatment, the shut down of these plants without significant cost to the stockholders, premature shut down is likely. We, too, are experienced in this matter.

Our Board of Directors, when they voted to shut down the Yankee plant, assumed that because of the excellent operating record of the Yankee plant for its thirty-two years, the stockholders' investment would be protected to a large degree. Under a rate case which we currently have before the Federal Energy Regulatory Commission, that assumption has been called into question. Although Yankee made the decision to save consumers over $100 million, the federal regulator, in his opinion to the FERC Commissioners, recommended that this savings to consumers be rewarded by essentially eliminating all of the equity of about $22 million that the shareholders have in the Yankee Atomic Electric Company. This will become, if this decision stands, a serious disincentive to premature shut down of plants that may not be economic extending the time which these plants will operate.

In my personal opinion, to answer the question of the longevity of these plants is more an answer to what will the future demand for electric power be. If the demand continues to increase, all forms of generation will be needed. If the need is low or alternative power producers, such as IPPs, develop relatively low cost, quick to build, easy to finance generating capacity, one can expect more premature shutdowns of existing nuclear and non-nuclear facilities.

I recently gave a talk to the local American Nuclear Society chapter entitled, "When Is a Trend a Trend?" This talk addressed the shutdowns of San Onofre, a 450 MW electric plant in California, Trojan, an 1100 MW electric plant in Oregon, and the Yankee Rowe plant, a small 185 MW plant in Western Massachusetts. In that talk, I listed the similarities in each case that led to a premature shutdown. They are: regulatory uncertainty, lower replacement power cost, unpredictable future cost, good financial offers made by the regulators, and hassle factors. Interestingly, environmental externalities were calculated but ignored which would have favored continued operation. I also described a "plant risk profile" for premature shutdown. The profile listed characteristics which if a plant was experiencing, put the plant in risk of being prematurely shutdown. They are: a plant which experiences consistently high capital additions; operating and maintenance costs exceeding inflation; a plant in a least cost planning or integrated resource planning state; a plant in a region of aggressive IPP developers; capacity factor of less than 70%; active political involvement; and a plant with "non-standard" NRC issues.

As you can see, there were no technological limitations listed. If the financial regulator says, "Let's make a deal," most utilities would likely make the deal and shut down their nuclear plant rather than go through the hassle of continuing to run the facility.

ECONOMIC PERFORMANCE FACTORS

Let me take a few moments and examine the factors of economic performance. Much attention has recently been paid to the escalation of nuclear power costs over those of the alternatives. Great pride is being taken by the nuclear industry in that they have finally flattened O&M costs per kilowatt hour. However, if one looks behind the data, one sees that the reason for the flattening in cost has been improved electrical output from these stations and not necessarily any significant reduction in the cash outlay for O&M. The industry has recognized that this continuing escalation which had historically been, in the last few years, 12 to 15% per year, needs to stop. They are now beginning to take significant steps at controlling staff size and O&M costs to maintain their competitive position if they can.

One of the key issues for the industry in fighting to reduce the O&M costs is the level of staffing compared to other alternatives. Shown on Figure 2.1 is a chart prepared by a senior executive of The Southern Company, in which he compares a comparably sized coal generating station and a nuclear plant of his utility. He makes the following assumptions for both: the labor costs rise by 5%, and all non-fuel costs rise by 4% with no escalation in fuel costs. He then projects into the future the current competitive cost of the two technologies. As you can see, the cost of nuclear power becomes noncompetitive in just a few years because of the very high dependence on people required to operate nuclear power plants. Figure 2.2 shows that roughly 55% of the costs associated with operating a nuclear power plant is direct labor compared to only 17% for coal. This is a major factor leading to nuclear power's high O&M cost escalation.

We, at Yankee, operated a small nuclear power station. When we started, we had 69 people to operate a 185 MW plant. When we shut down we had 220 people operating this same plant. Figure 2.3 shows how Yankee's staff increased over time due largely to changing regulatory requirements. On average, in the industry, to run a 1,000 MW plant a staff of close to 1,000 people is employed. It is not clear whether that many people are required to operate and support a thousand megawatt plant. It is my contention that this is where the savings in operating costs can be made.

The average capital expenditure for these nuclear plants runs, on an annual basis, from $10 to $50 million a year, way out of proportion to other technologies. Some of it is regulatorily driven, some of it is reliability driven, but, as a practical matter, it is much too high to support a competitive nuclear power plant. Utilities today are significantly curtailing their capital expenditures and taking a very hard look at the types of changes they are installing for value and not simply regulatory compliance.

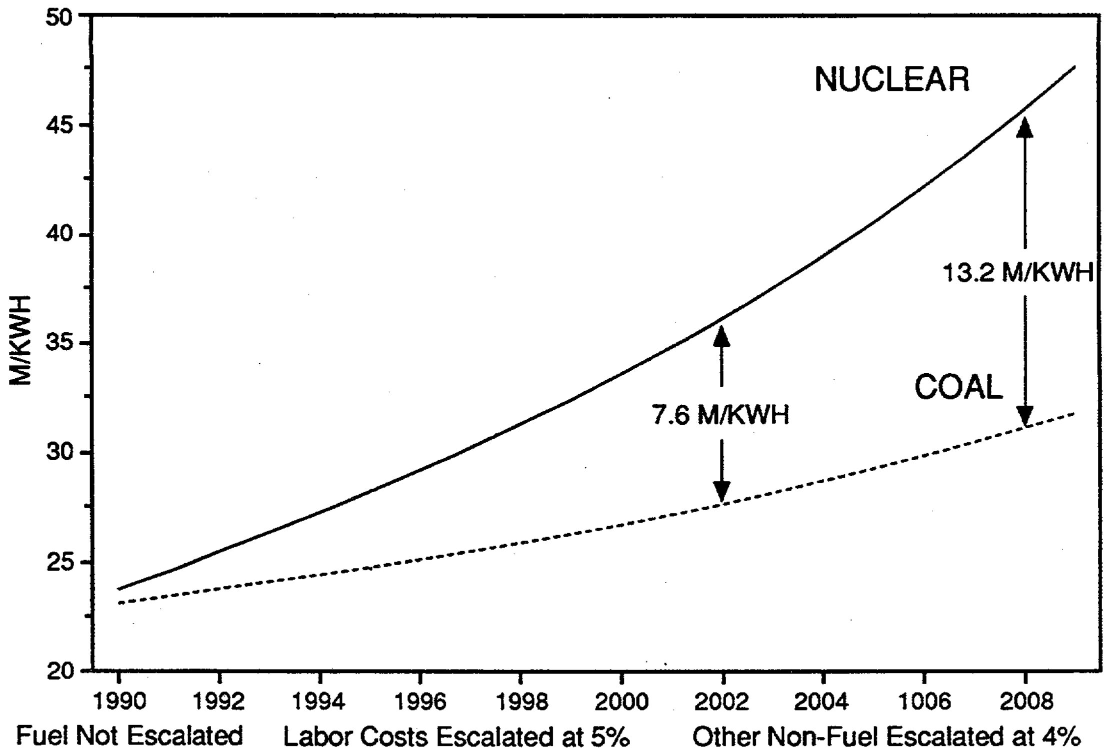

Figure 2.1: Escalated Total Production Costs – U.S. Industry Median.

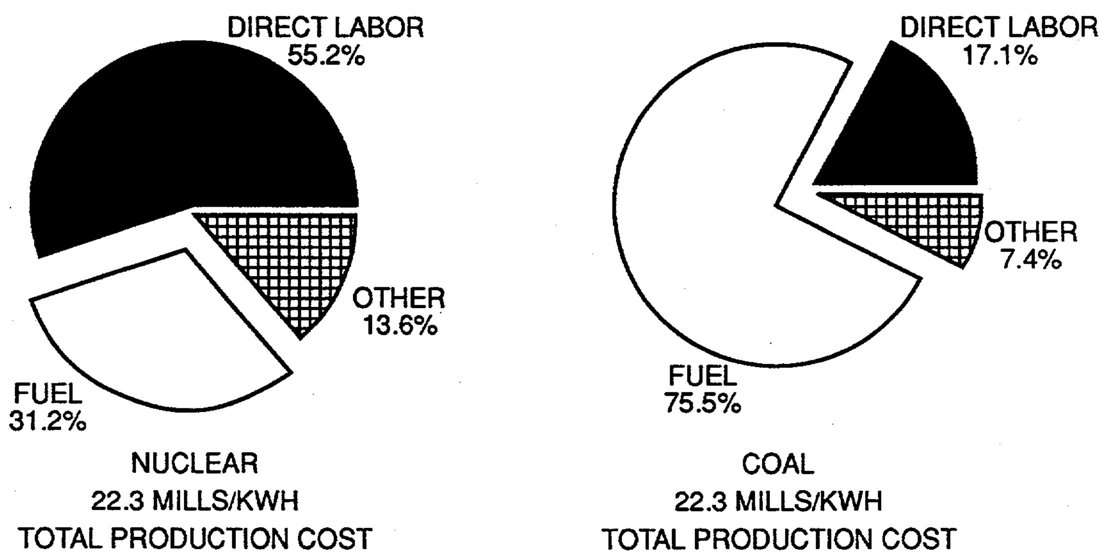

Figure 2.2: 1990 Production Costs – U.S. Industry Medians.

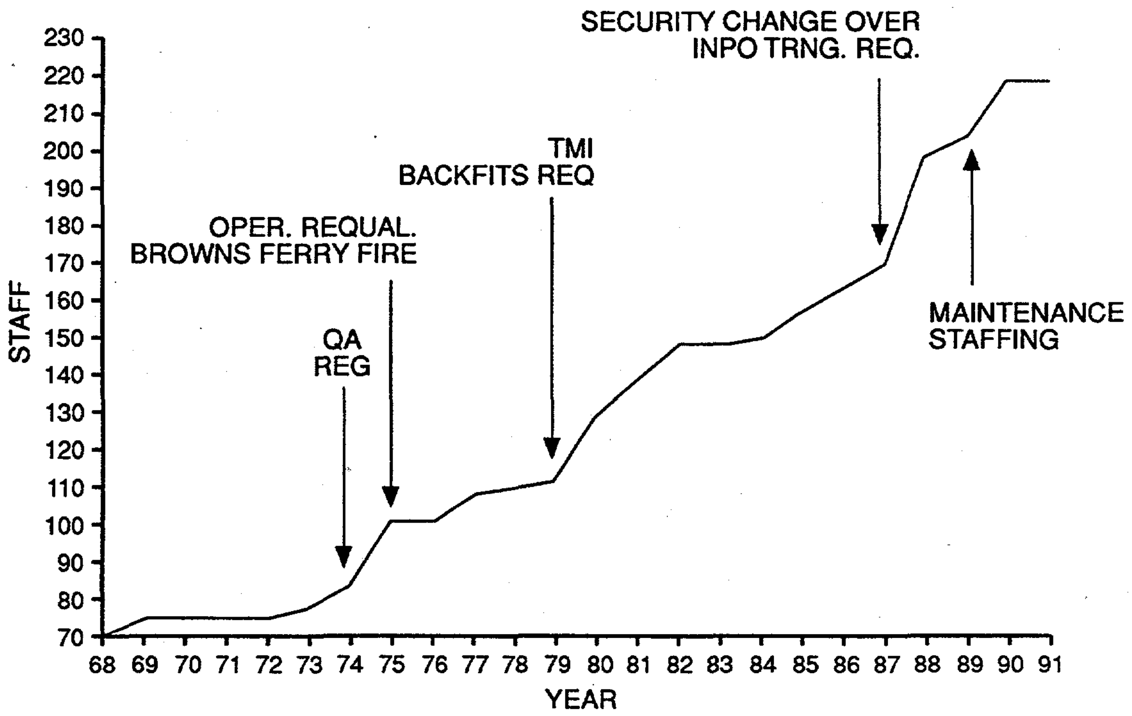

Figure 2.3: Yankee Plant Staffing Levels.

NRC requirements have been historically used as the reason for the failings of the nuclear industry. While, no doubt, the NRC has been a significant driver in the increasing cost of nuclear power, a recent INPO evaluation showed that there are factors of two to three times difference in staffing for similar sized and situated plants between one utility and another to comply with the same NRC requirements. Thus, while NRC may initiate new requirements, it is how utilities respond to those requirements that determines, in many ways, the competitiveness of that particular facility.

In the decision to shut down a nuclear power plant or keep it operating, the issue of regulatory uncertainty weighs heavily on the decision maker. Not knowing where we stood or how much it was going to cost to resolve an issue, was a very big factor in Yankee's decision to shut down as it was with Trojan. The regulatory instability that the nuclear industry has had to endure for most of NRC's existence needs to be stabilized before we can answer the question of how long nuclear power plants will operate with any certainty. Although the NRC is making some effort at providing some clear direction and criteria for operation, they continue to go beyond regulations in terms of interpretations and requirements that, in the minds of the decision maker, create an unbounded uncertainty in terms of financial exposure. This factor reinforces management's decision to shut down a plant prematurely.

Other factors which affect economic performance include the hidden taxes imposed by the federal government in recent years as fees for "services" rendered. We recently completed a survey of New England nuclear plants and found that within the last three to five years these so-called fees, which are unique to the nuclear industry, cost each plant about $10 million per year. This amounts to 10% of the cost of O&M that a typical large plant might experience. These fees include paying 100% of the NRC budget, Federal Emergency Management fees, Department of Energy fees for waste disposal, and decontamination and decommissioning costs for government enrichment facilities that were originally built for the weapons program. These fees for government regulation are not borne by the alternatives. Government has yet to impose service charges, i.e., hidden taxes on the production and/or regulation of coal, oil or natural gas.

As it pertains to fuel price, the nuclear industry is more fortunate. The cost of uranium is literally dirt cheap today. From a high of $40.00 a pound in the mid-1970s, the price is hovering around $10.00 in today's dollars. This is due largely to lack of demand. Only 30% of the production cost of electricity from nuclear plants is fuel while it is about 75% for coal or gas.

THE UTILITY INTEREST

The determination as to whether or not a utility will choose to prematurely shut down a plant or continue to operate it is driven by the cost of alternatives. Alternatives being, in the utility's mind, how much does it cost to sell electricity. Utilities typically do not care whether it is generated by oil, coal, natural gas, solar, biomass or hydro, or whether it is purchased under contract for resale. Their business is the selling of electricity.

The utility industry itself is also undergoing rather dramatic changes. New initiatives proposed by the Federal Energy Regulatory Commission and the Energy Policy Act of 1992 are forcing utilities to relook at their entire business and examine what business they are really in. With the crucial issues of transmission line access, retail wheeling, competitiveness, the disincentives to build their own generating plants through the integrated resource planning that exists in many states, utilities of the future, in response to these external factors are going to be quite different than the utilities of today. We have already observed the creation of conglomerate utilities that are finding that they need to split up their operations into separate business units from generation to transmission to retail sales. They are also looking to external markets for their expertise in countries such as Argentina and in Eastern Europe. Thus, the question as to who will build the next nuclear plant or who is interested in continuing to run the existing nuclear plants is open to question.

Federal and state regulatory policy has a significant impact on the question we are attempting to address, but more fundamentally on who will be the builder and operator of future electric generating plants. There are some who advocate that the new nuclear plant or even existing plants be run for utilities by a managing agent. This concept, which was originally started with the construction of the Yankee plant, is presently being used at Seabrook as well as other plants around the country. Under this concept, the utilities may own the facility, but its operations are delegated to a company whose only business is running that plant to be sure that all the attention is focused on that facility and not the additional concerns of meeting customer demand, transmission line access and the other issues the utility industry is facing. This is likely to be the wave of the future. If utilities decide to go the managing agent concept there is probably a higher likelihood that the plants will continue to operate because of the managing agent's focused attention on the reliable operation of the nuclear plant. However, we are in the very early stages of this concept for the industry.

LICENSE RENEWAL

On the assumption that the plant is reliable, the issue of relicensing or renewing of licenses comes up. As I mentioned earlier, Yankee was in its thirtieth year of operation, ten years prior to expiration of its present license, with an excellent operating record, 10% above the national average, when the company decided to explore the feasibility of license renewal. License renewal becomes important for plants that approach the end of their present license due to the fact that if significant capital expenditures are required to continue to operate such as the replacement of steam generators or turbines or even the generator, the time to write-off the investment becomes extremely short which may have a significant cost impact on the price of electricity. Thus, the relicensing option, which would allow for plants to extend the amortization of significant capital investments, may be necessary to assure that plants can complete their existing licensing term on an economic basis.

In my opinion, license renewal should be pursued early enough such that the utility can complete its initial forty year licensing term. Although plants may choose not to operate for the full term of the extension, the flexibility that the extension period offers, provides the additional assurance that forty years can be achieved.

License renewal is also very important to the future of the industry since it keeps the nuclear option open longer for the next generation of nuclear plants. According to Figure 2.4, there will be a significant decline in the number of operating reactors, assuming the plants run to the end of their license, by the year 2013. The capacity must be replaced, but it is much too early to think about replacing it now. Thus, with license renewal, the future of the nuclear option becomes brighter.

I would like to distinguish the difference between life extension, relicensing and renewal. Life extension is a term used to describe increasing the operating life of particular components. Preventative maintenance and refurbishment can be done to improve the life expectancy of individual components. Relicensing is a term the Nuclear Regulatory Commission likes to use as their concept for renewing of licenses which the Atomic Energy Act allows. In their view of renewal, they believe that you need to issue a new license, i.e., relicensing. Under the Atomic Energy Act definition and the industry position, renewal is just a continuation of the existing license. These differences have significant implications on the process used to allow plants to run beyond 40 years. If the NRC staff position persists, that is renewal should be a new license, license renewal may, in fact, be dead because utilities would not want to undergo the tortuous

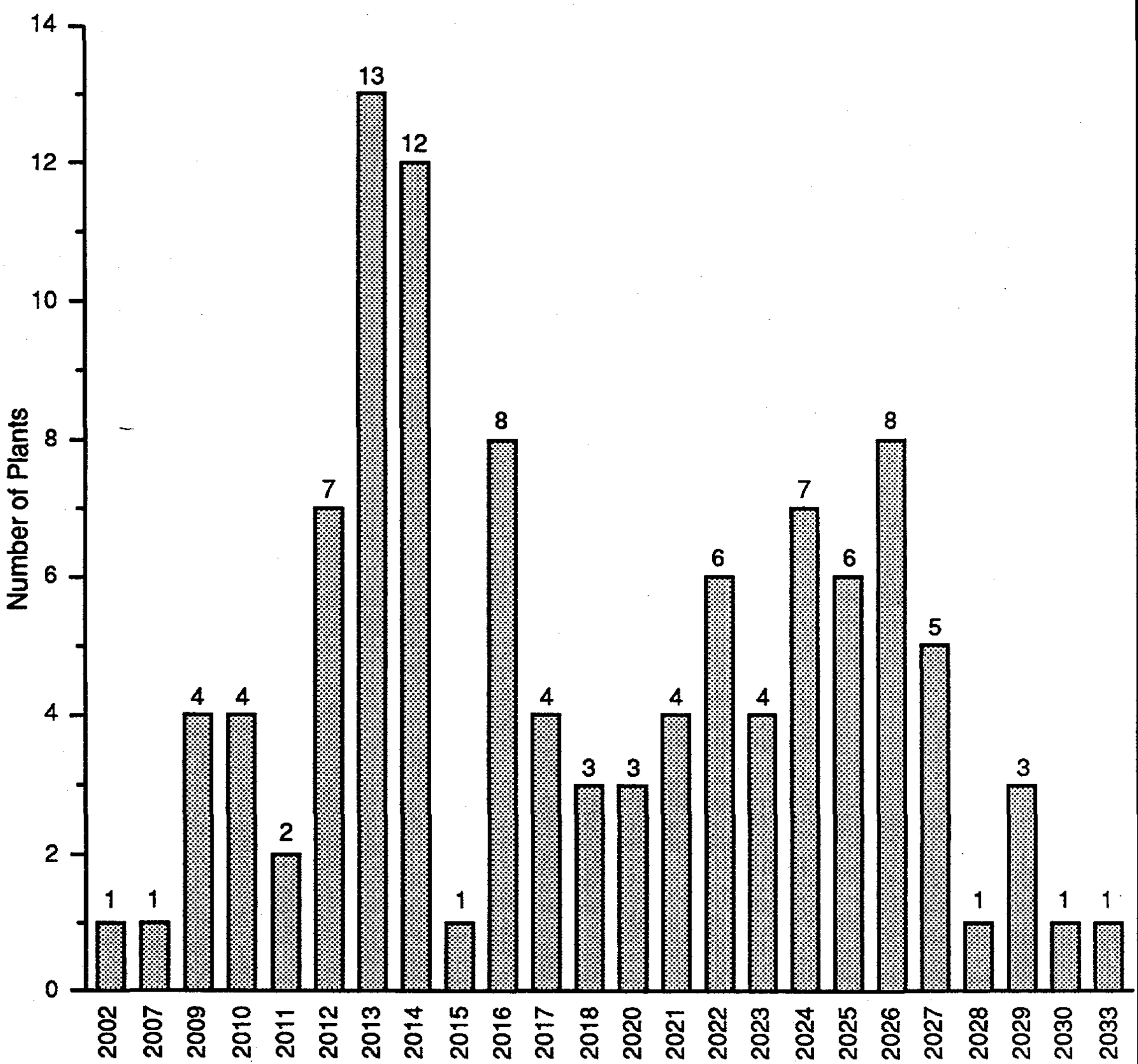

Figure 2.4: Number Of U.S. Nuclear Plant Licenses Expiring From The Year 2002 – 2033.

process of relicensing a power plant that has been operating safely and reliably for 30 to 40 years.

The fundamental justification for license renewal is based on several factors: the technical capability of the plants to run beyond forty years; the generating capacity that would not have to be built is real; a measure of reliable performance is available; capital costs for continuing to operate this plant could be spread out over the renewal term; extending the licenses of existing facilities is cheaper than building new plants; and it allows a longer time to collect the decommissioning costs to keep the cost of power lower. These are very strong economic arguments for renewal provided the licensing process allows it to be done efficiently and cost effectively. As long as existing nuclear plants continue to operate, the nuclear option is preserved and the technology base is maintained as is the electric generating capacity base since the construction of replacement capacity is difficult and costly.

Thus far the record for license renewal as it affects the regulatory process is not good. The process that the NRC staff has developed in response to the license renewal rule is extremely complex, overly based on paper and process, factoring in little of the existing regulatory oversight or performance in the regulation. The NRC is now reviewing their regulations completely since utilities have told the NRC Commissioners, that if the process stays as is, there is little likelihood of any plants submitting applications for renewal. In fact, Northern States Power, for the Monticello plant, chose not to submit their application because of the license renewal regulations as implemented by the NRC.

PERSONNEL SUPPLY

What would happen if, as some have forecast, up to 25 or 30 nuclear plants prematurely shut down for economic or other reasons in terms of its impact on personnel supply? The industry has already suffered from a diminished interest in graduates pursuing nuclear careers because of the prevailing perceptions that the nuclear industry is dead or it will soon die. After all, the anti-nuclear community is correct, there has not been a new nuclear plant ordered since 1978 and that is a pretty tough business climate to be in if one is looking for a long-term career. With the additional shutdowns in the industry, my suspicion is that fewer and fewer engineers will want to pursue nuclear technology either as a career or as a business.

In 1973, when 5% of the nation's electricity was generated by nuclear power, there were more than 70 University research reactors of the U.S. Twenty years later, although the percentage that nuclear provides to the nation's electricity has more than quadrupled; the number of University research reactors has been nearly halved to 37 (Oct. 1993 *Nuclear News*, page 55).

There are 50 U.S. institutions (down from 55 last year as five suspended their programs or awarded their last degrees) that offer a major in nuclear engineering or an equivalent discipline that qualifies the graduate for nuclear engineering positions based on a recent survey by the Oak Ridge Institute of Science Education for the DOE (Oct. 1993 *Nuclear News*, p.48).

Apparently the trend is changing, however. Whether it is due to improving performance of nuclear plants since the Three Mile accident or whether it is because of environmental concerns such a global climate change or acid rain, there apparently appears to be a turnaround in university enrollment in the nuclear engineering programs.

A seven year trend of decreasing undergraduate and graduate enrollments in nuclear engineering programs reversed itself last year with an increase of 8% at the undergraduate level and 4% in Masters programs. In 1992, there were 1497 students enrolled in nuclear engineering programs; 815 enrolled in Masters programs; and 646 in doctoral programs in the U.S.

Nuclear Engineering degrees, as a percent of all engineering degrees awarded in 1992, represented less than 1% of undergraduate (384 B.S.) and masters (212 M.S.) degrees, and about 2% of the Doctorates (135 Ph.D.s) according to the 1992 Engineering Workforce Commission Report (Oct. 1993 *Nuclear News* p. 48).

Although the number of students from the enrollment heyday has dropped approximately 50% in all types of graduate education in nuclear science and technology, that number appears to have stabilized and is now growing. As a practical matter, however, nuclear technology is fundamental to the engineering disciplines of mechanical, electrical and civil engineering. The nuclear specialists are the reactor physicists or safety analysts. Requirements are small in a typical utility. Thus, although the number of graduates has declined substantially, the need has also declined. The need is for good solid engineers who understand how things work and the basic design of systems—pipes, valves, electrical systems as well as structures. Thus, although the number of graduates has decreased, the impact has been small on the day-to-day operations of nuclear power plants. The concern, however, is the ability to attract good people to enter the nuclear field and not the lack of people.

Due to the lack of new orders for nuclear power plants and the burdens of being a supplier to the nuclear industry, we have also seen a decrease in the number of suppliers that are qualified to provide safety grade equipment. The nuclear vendors and suppliers are essentially in the spare parts and service business.

UTILITY INTEREST IN NUCLEAR POWER

As to the utility interest in building new nuclear power plants, I would have to say there is little now. The utility industry has, however, embarked upon a strategic plan to build the next generation of nuclear plants in the future.

As you may be aware, the industry and the Department of Energy are jointly funding, through the Advanced Reactor Corporation, two types of standardized advanced nuclear power plants. The first is a simplified Westinghouse 600 MW pressurized water reactor that has many passive features and the second is a General Electric 1300 MW boiling water reactor that is presently being built in Japan. The utility industry is investing over $100 million in these two projects. In addition, ABB-Combustion Engineering is working on design certification of its System 80+ 1300 MW pressurized water reactor. General Electric, with international utility support, is also developing an advanced 600 MW simplified boiling water reactor.

The crucial part of the industry plan to build the next plant calls for early site certification. The industry is finding it very difficult to come up with volunteer sites to do the environmental qualification of those sites. This difficulty in finding utility volunteers underscores the difficulties that the next generation plant will encounter. If no utilities are willing to step forward to pre-qualify some candidate sites, it is hard to forecast the construction of a new plant.

I think it is fair to say, however, that given the changes in the utility industry that are now taking place, future generating options are not being given a great deal of attention simply because the demand for electricity in most parts of the country is not there. What demand there is, is being met, in most cases, by independent power producers or industry backed generating companies that can apparently build power plants without great difficulty. It is also not clear that as the utility business restructures itself, that they will build their own generating stations in the future. These developments are in some ways fortunate for the nuclear option since it buys the industry time to develop the technology as an option for future decision makers, be they utilities or some other consortium of companies.

The reason for utilities' reluctance to go down the nuclear path is obvious. In the past decade, utilities have canceled more than $20 billion of nuclear plant investments, $14 billion of which was charged to investors. Even today, the state regulators, who have fully participated in the decision to build plants when demand was high, are disallowing from rate base entire plants because they are not perceived to be used and useful even though they are generating electricity. In addition, the continuing regulatory changes, escalating costs and the attention that nuclear power plants require from top management takes away from other aspects of the utility's core business.

Utilities that are interested in nuclear power are only looking at it as an option for the future; namely, doing enough engineering and design to qualify it, from the standpoint of economics, to be included in the future mix of options such that when a decision needs to be made there is some basis for the cost numbers. However, if a nuclear power plant is built in the future, the process must be different than the process used to build the first generation of nuclear power plants. Utilities will no longer be the test beds for vendors or designers and taking all of the risk. The financial risk of building the next generation of plants will be shared with the developers and vendors. Whether they are willing to put money behind their technology remains to be seen.

There is a fundamental belief among utility CEOs that nuclear power is environmentally our best alternative to meet the needs of a sustainable environment. However, they are no longer willing to take the risk by themselves. There is a need for a renewed commitment to nuclear power by the nation as a means to clean our air and our water while reducing our dependency on foreign sources of energy. Nuclear power cannot be portrayed as an alternative of last resort as previous administrations have cited it if they hope the utility executives will chose it. In President Clinton's plan to reduce the greenhouse gases, he acknowledges the role nuclear power needs to play. More of this type of support is needed if nuclear is going to make a comeback. Ultimately, the decision will be financial, not technical, and it will be based on politics.

TECHNICAL INNOVATION

The funding base for technological innovation is declining. Utilities are hunkering down, attempting to reduce their costs, to keep their plants competitive. Utilities want proven products with warranties and guarantees that mean something. They do not want to pay the cost of replacing a steam generator after ten years which was supposed to last for forty years.

Funding from the vendors will also decline as they see fewer opportunities for selling the products that they develop in a declining marketplace. Once there is a renewed commitment to nuclear nationally; once it is clear that the construction of a nuclear power plant can be done competitively, I expect this funding base to increase, but not in the short term.

The time horizon for technical innovation in the nuclear industry ranges from five years to never. The regulatory process discourages technological innovation. The utility industry has long looked toward digital control systems as a means to improve the operation of the plants. The hurdle rate that NRC places in front of a utility seeking to improve control systems with digital technology is enormous. As recently as this summer, the NRC put out a special notice to utilities identifying the process and the limitations by which digital control technology would be allowed. The Chairman of the Nuclear Regulatory Commission who, himself, is well experienced with digital control systems, was embarrassed by his staff's reaction to technological innovation, particularly in this field.

Thus, even if there were great ideas out there, the implementation in existing plants would be a long time in coming. As a matter of fact, the regulatory process freezes technical design innovation at the time of licensing which may be ten years prior to operation. Utilities are not likely to risk making design changes for fear of affecting the operations of their plant due to the actions of the regulator.

CONCLUSION

How does one summarize all the points made in this paper concerning how long will the current nuclear plants operate and its implications? I recently found an article that appeared in the *Journal of Reactor Science and Engineering* in June of 1953. It was written by Admiral Hyman Rickover on the subject of "Paper Reactors, Real Reactors." Allow me to contrast the two using the Admiral's words:

> "An academic reactor or reactor plant almost always has the following characteristics: 1) It is simple; 2) It is small; 3) It is cheap; 4) It is light; 5) It can be built very quickly; 6) It is very flexible in purpose; 7) Very little development is required—it will use mostly off the shelf components; 8) The reactor is in the study phase. It is not being built now.
>
> On the other hand, a practical reactor plant can be distinguished by the following characteristics: 1) It is being built now; 2) It is behind schedule; 3) It is requiring an

immense amount of development on apparently trivial items—corrosion, in particular is a problem; 4) It is very expensive; 5) It takes a long time to build because of the engineering development problems; 6) It is large; 7) It is heavy; 8) It is complicated."

I would like to add a third category to the Paper Reactor, Real Reactor list—an Operating Reactor: 1) It is built; 2) It works; 3) It took a long time to build; 4) It costs more than it needs to; 5) Rickover was right; 6) However, it produces electricity.

The moral of this story is what looks good on paper may not be good in practice. Before we prematurely shut down existing nuclear plants in favor of paper plants or paper economic studies using integrated resource planning, we should carefully consider the existing capacity to produce electricity that these plants represent.

The challenge for the utility industry is to reduce the cost of operating these plants by beginning to run plants like a business. Nuclear industry management must regain control of their business by focusing on how they can make their operations more effective, reengineering their work processes to be sure that each step adds true value and then downsizing without compromising safety. It can be done and if done, nuclear power can operate well beyond their artificially established 40 year operating licenses.

RESPONSE TO A.C. KADAK

HOW LONG WILL THE CURRENT NUCLEAR POWER REACTORS OPERATE?

Mason Willrich

How long the current generation of nuclear power reactors will operate depends on factors intrinsic to the nuclear industry, but is also strongly influenced by extrinsic factors. Dr. Kadak provided a comprehensive discussion of the intrinsic factors. I want to set that discussion in a larger context:

- Evolution of nuclear power in the United States; and
- Extrinsic factors strongly influencing, if not determining, the future evolution of nuclear power in the U.S.

EVOLUTION OF NUCLEAR POWER IN THE U.S.

Since the Three Mile Island accident, nuclear power has been on the defensive. U.S. nuclear utilities adopted the strategy of "safety through NRC compliance," regardless of cost.

Most of the plants in construction when Three Mile Island occurred were eventually completed under this safety at any cost regime. As a result, utilities were saddled with huge, high-cost investments producing large blocs of 8-10 cent power. While this was tolerable as oil and gas prices spiked in 1979-80, it was viewed with alarm as oil and gas prices crashed in 1985-86.

State regulatory commissions began disallowing large amounts of the costs of nuclear plants. Where this occurred, existing utility shareholders were badly hurt and utility management became very risk averse regarding the construction of new generation facilities. To the extent that disallowances made the costs of particular nuclear power plants more competitive with lower cost alternatives, new utility shareholders were better off.

Meanwhile, nuclear power became firmly embedded in the traditional model of the U.S. utility industry:

- Monopoly franchise;
- Tightly integrated generation, transmission, and distribution; and
- Increased earnings for shareholders based on increasing the size of the rate base.

EXTRINSIC FACTORS INFLUENCING THE U.S. NUCLEAR POWER INDUSTRY

Even before Three Mile Island, new entrants were clamoring to be given a fair chance to compete against the old model utility. These new entrants focused on generation; specifically, small plants utilizing new, often experimental, technology.

The Public Utility Regulatory Policies Act of 1978 (PURPA) provided the framework for the entry of new participants into U.S. electric power markets. Utilities were required to buy power offered by qualifying facilities (QFs) at avoided cost. QFs are either small power producers or cogeneration plants. In either case, utility ownership is restricted to 50%. Avoided cost determinations were made at the individual state, not federal, level. Some states (California, later Massachusetts) favored setting high avoided cost prices. Other states did not. However, public utility commission-determined avoided costs have now been replaced by market based prices determined by competitive bidding as the main means for utilities to procure additional electric generation. Between 1990 and 1992, more than half of new additions to generation were made by independent power producers, primarily QFs.

With the enactment of the Energy Policy Act in October, 1992, the old model utility was effectively scrapped. A new category of electric power producers, exempt wholesale generators (EWGs), was created. EWGs provide more flexible options than QFs for competitive generation because EWGs are size and technology neutral and there are no restrictions on ownership by a utility affiliate. In addition, the Energy Policy Act provided all generators with access to transmission grids for wholesale transactions.

As it confronts removal of these final barriers to a much more competitive electric supply market, the electric utility industry today is balkanized, but can be broadly divided into two camps:

- Just say "no" to change utilities, often nuclear utilities with very high cost plants locked into utility rate base, who fear that their investment in these costly plants will be stranded; and
- Progressive utilities willing to adapt and compete in a new environment.

THE NEW REALITY

Current markets for electric power in the U.S. are characterized by:

- Intense competition in wholesale generation
  - Nuclear is 7-10 cents per kilowatt hour (kWh)
  - New coal is about 5 cents/kWh
  - New wind is 5-6 cents/kWh
  - Biomass is 4-6 cents/kWh
  - Natural gas is 3-4 cents/kWh
  - Energy efficiency is 2-4 cents/kWh, but not very measurable
- Slow growth in demand due to economic recession, adding to competitive pressures
- Retail wheeling as a major threat
  - The movement toward competition and customer choice in retail markets is driven by the fact that utility customers all face global competition and strong pressure to reduce costs. As their trump card, energy intensive customers retain the option to move from high cost to lower cost electricity areas.

CONCLUSION

How long will the power reactors now on line operate? It depends.

I believe that voluntary early retirement of weak performers will continue, resulting in high-grading of the U.S. nuclear portfolio. Recently, for several nuclear plants such as Yankee Rowe, San Onofre One, and Trojan the prospect of large capital outlays coupled with an ongoing record of below-average capacity factors and high operating and maintenance (O&M) costs became de facto plant life decisions.

Are there more Trojans out there? Probably. Certainly most nuclear plants face the need for major capital improvements, such as replacement of steam generators, if they are to operate for a full 40 years and perhaps an additional 20 or so years associated with license renewal. As many as 27 units, representing 25,000 MW in the U.S., are considered vulnerable due to high O&M costs. Of these 27, seven units, representing about 5,000 MW, are potentially in need of major capital expenditures involving steam generator replacement within the next five years.

Two open issues remain in regard to decisions on the voluntary early retirement of nuclear plants:

- Will incremental investment in existing plants be evaluated over the remaining years of the plant license or over the plant's economic life?

- Will state PUCs be generous to utility shareholders in the cost recovery allowed for early retirements?

I also believe that involuntary write downs of the asset value of high cost nuclear plants may occur. The issues in regard to involuntary write downs are as follows:

- Are the system power costs of nuclear utilities high and vulnerable to competition?
- Will utilities with high cost generation be forced to take write-offs to make themselves competitive?
- Will state PUCs remove existing generating plants from utility rate base?

Some partial answers to the first question are emerging. There is growing recognition that today's plants will remain economically viable only if additional capital investments are controlled and O&M costs are brought down.

The industry has done extensive analysis to determine what caused the sharp cost increases. Regulation was certainly one of the drivers. Consistent with a recent Presidential Executive Order to "reform and make more efficient the regulatory process," the Nuclear Regulatory Commission is working with the nuclear industry and individual utilities to reduce regulatory burden. The provisions in the Energy Policy Act for streamlining the plant licensing process should also help.

The industry itself also bears some responsibility for the 10-15% per year O&M cost escalation of the 1980s, which have just recently begun to slow. Many companies have not controlled staffing levels, particularly in areas like engineering and security, as well as they might. One indication of the industry's concern about the impact of O&M costs on the economic viability of nuclear power is the development of the Industry-wide Initiative to improve plant performance. Recent efforts by several utilities to reduce nuclear plant staffing, a primary component of O&M, provide an example of a growing effort to control costs.

Perhaps if the cost issue is dealt with, the necessity to deal with the last two questions will be diminished. How long will the current nuclear power reactors operate? It depends.

HOW LONG WILL THE CURRENT NUCLEAR POWER REACTORS OPERATE?

DISCUSSION

Public Policy Analyst:

I think it is important for folks to realize that regulators either will not, or cannot, protect regulated facilities from the forces of competition. Whether they will not or cannot does not matter, protection will not occur. Thus, over time you will have a regulatory system that will become as unforgiving and as ruthless as the marketplace. It is time for the utilities to get ready for that reality.

Regarding continual operation of a nuclear power plant, either at the end of its first license or when a utility is faced with a major capital investment needed to keep the power plant running, even through to the end of its existing license, I think that a necessary, but not sufficient condition, for the utility to keep that plant in service would be the cost of producing energy. It would depend upon the remaining undepreciated investment in the plant. It would be necessary at that point to examine the operating costs of the plant, and to treat the plant as though it were a stand-alone unit with all of its remaining capital and the operating costs, and to look realistically at the marketplace, meaning not only the utility's own service territory, but also the wholesale electricity marketplace, in order to determine whether the plant could make it on its own as a business venture. If the answer is no, you have to shut the plant down, because the regulators are not going to let you make the profit on the plant if it is uneconomical. The most that you can hope for is that you would be able to earn a return on the plant.

I suggest that a utility thinking that its plant is worth continuing in service should do their best to move it out of the rate base, and to try to run it as a separated unregulated entity. Then at least, the company would have the potential for some gain in the event that the plant were indeed profitable. If you keep the plant under regulation, then your potential for gain is zero, because you will have a regulated rate of return; but the potential for loss will always exist because of the possibility of disallowance. So, I offer this as an example of a way of thinking about the economics of keeping a plant in service.

Now, there are many other decision factors which I have not mentioned. These include hassle factors and safety regulatory observers. It seems to be a necessary but not sufficient condition that the owner of a plant look at it realistically; as though it were a stand-alone business, and to see whether it could survive in the face of all cost factors.

U.S. Nuclear Power Industry Professional:

I would like to comment upon the problem of increasing nuclear power costs. If you look at the nuclear power industry, you see that our costs are driven mostly by operations and maintenance (O&M). Most of the plants that operate do so relatively well, operating at close to full capacity. The well publicized problems of nuclear power are determined more by the few plants that operate at relatively high cost and at relatively low capacity factors. You find that the few plants that operate at average production costs of 60 mills/kW-hr are balanced by most of the plants which operate at much lower costs. I conjuncture that it is easier to improve plants that operate at a capacity factor of 60%, at 60 mills/kW-hr, to bring them down to 30 mills/kW-hr rather than to take five or six plants, each operating at 70% capacity factor and 20 mills/kW-hr, and to improve them up to, say, 15 mills/kW-hr, and 80% capacity factor. So, improving the performance of a few plants is a far easier way of improving the industry. That is a much better way to improve the economics of the industry, and that is probably an area worth pursuing.

I would like to second the notion of operating the plants as independent cost centers. In controlling costs, it would be valuable to determine the staffing truly required to operate the plant as compared to the way plants are now staffed. One of the major factors of increasing staffing levels is the growth of the engineering staff. Regardless of efforts for licensing renewal, I think that we should assume that engineering staff levels at nuclear power stations will continue increasing as they have increased over the past ten years. However, some current activities to control O&M costs may limit staffing levels, and contribute to rationalizing the staff requirements.

Another plant cost-related factor that has received attention recently concerns overhead costs charged by the utility; charges to the power station that have nothing to do with the actual operation of the station, or with the cost of the energy produced by the station. I have seen recently figures that go anywhere from 30% to 60% of the energy production cost contributed by overhead expenses. One way that the costs can be controlled is by reducing 10 or 20% of a station costs that arise from the utility overhead and are assigned to station operations.

Finally, as has been mentioned before, the major factor contributing to costs is that of the increasing cost of manpower. If this trend could somehow be controlled or reversed, as part of an initiative that the industry is now starting, in addition to obtaining an improved capacity factor, then costs could be brought under control. The economic hope of utilities is the reduction of expenses, on the one hand, as well as the improvement in the capacity factor for energy generation on the other.

Regarding the plant life extension, I think that we are in the situation that some existing plants, mostly the high cost plants, cannot afford to shutdown yet because of the high capital cost that is not yet amortized. We could talk about $4 billion of yet unrecovered capital investment in a plant. It is difficult at this time to strike a deal for that amount of unrecovered costs, so, probably those plants will have to continue operating for a longer time in order to allow us sufficient operation upon which to base any economic cost recovery.

U.S. Nuclear Power Industry Professional:

I am among the group of people who believes that the future of nuclear power depends upon public acceptance. I want to congratulate Prof. Golay on a Conference where alternative viewpoints are expressed. I think that this kind of meeting is extremely important as we spend too much time preaching to the choir.

About 20 years ago I received a very indignant call from the Vice President of Public Relations of our local utility. He was particularly distressed with the Boston Globe, because the Globe just had had an editorial that morning that had congratulated the Boston Edison Company on the Pilgrim Plant, the first nuclear plant in the U.S. As we all know, Pilgrim is much younger than the first plant. My subsequent point is, if you look at that date, that was the same time when we only had 65 people running the Yankee Rowe Nuclear Power Plant; I believe there is a link between the two factors.

International Nuclear Power Industry Professional:

In Taiwan 95% of the energy supply comes from foreign countries. We first built a nuclear power plant in the 1970s. We now have built six units. However, in our country the nuclear reactor license duration is only ten years. So, every ten years we have to submit our operation and maintenance record to our Atomic Energy Commission for a new license. After the Three Mile Island (TMI) and Chernobyl reactor accidents, our general public has become very concerned about the quality of nuclear safety. So, about five years ago our company (Taipower) set up a nuclear operation improvement program. A major goal of the program is to reduce the [unplanned] reactor trip frequency. During the past five years, we have had an average of 18 reactor trips per year at our six units. Our 1993 objective was to reduce the number of reactor trips to six. During the past year, our record was seven trips and in this year we have had 30 trips to this point. So, in April we got a new vice president in charge of nuclear operations. In our country, how long the current nuclear power reactor operation will go on depends upon our operation and maintenance record.

Academic Socio-Technological Scholar:

I would like to just make a general comment that I think applies to all of the Conference sessions so far. It seems to me that one of the chief problems that the nuclear industry faces comes from the tyranny of short-term commercial pressures over the long-term design and development choices. I fear that some of the same pressures seem to be at work today whether we look historically at light water reactors or the continuing development of breeder reactor technologies. I think the same problem appears in explanations for nuclear power plant operating licensing extension that rely on the sunk cost and the desire to revise questions that are already decided. It seems to me that market costs, not sunk costs, should guide the decision choices or licensing extension. Stated differently, design choices should be made looking forward rather than backward. To the extent that the public understands current nuclear power choices as being driven by efforts to satisfy the hopes for past investments and as driving license extension decision-making, the life extension decision is discredited.

U.S. Government Employee:

I would like to agree with what was just said. Also, regarding the commitments which the government is making for research and development, I and I think earlier speakers might have, implied that there is a commitment to breeder reactor technologies in the budget. This is a common misunderstanding. The people who participated in our grand debate this last summer have persisted in arguing that what we, in the DOE, were proposing to do is to develop the breeder reactor. Actually the liquid metal reactor (LMR) conversion ratio was equal to 0.7. In fact, the LMR actinide recycle program has the potential to turn the reactor into a nuclear waste burner. The potential of the LMR as a breeder should not be confused with what we are actually proposing. Since I am the person who, in a way, resurrected the LMR, I can say quite frankly that if it were just a breeder reactor that we are talking about developing, I would be the first person to cancel it. We do need to look, however, at the real problems which we are facing, included among which is nuclear waste management. I think one of the purposes of research and development programs is investigating new ideas and new applications for older ideas. So we should keep that in mind.

U.S. Nuclear Power Industry Professional:

Right now the industry is truly faced with a crucial decision concerning natural gas. I suggest that we need to work not only in our industry, but also to study what other industries are doing in their consumption of energy. I submit that natural gas probably is the most promising vehicular fuel for emissions reductions. We all know about electricity and, I suppose, that it will play a part in future transportation also. But I do not think that electricity is well suited for this role, and natural gas is. Well, if that is true, then it is crazy and tyrannical to have a situation where the only feasible decision available to a utility executive is to burn that potentially scarce and valuable natural gas to produce electricity.

Public Policy Analyst:

I would like to make a couple of points in response to the DOE. I was one of those witnesses over the past summer who testified before the Congress that the LMR was indeed a breeder reactor. I quote from a letter that J. Ahearne, who was chair of the Committee of Future Nuclear Power Development of the National Research Council, sent to two key members of Congress, Senator Johnston and Congressman Bevel, to clarify this point. I quote from the letter:

> "In the study, we note the advantage of the liquid metal reactor as a breeder. The LMR might be commercially competitive if a uranium fuel shortage limits the use of LWRs. ... If a shortage of uranium develops, your reactor could breed plutonium."

It went on further to say that the use of the LMR for actinide recycling had to be raised as a potential benefit, but it was concluded that the LMR's potential to alleviate some of the waste disposal problem of the fuel actinide recycling is at such a preliminary stage that this feature is considered to be justification for neither advancing the advanced LMR development program, nor delaying the waste repository schedules. I think that it is useful to have this clarification on record early in this discussion.

I would like to further raise this point with Mason Willrich. I was taken with his statement that he would favor nuclear power, if, among other things, a global proliferation framework were to exist in which proliferation risks would be made manageable and if they were being effectively managed. The questions I would like to put to him are: To what extent will these prospective shutdowns of nuclear power plants in the U.S. affect the uranium market? In other words, how much more uranium is there likely to be? How much surplus and dirt cheap uranium, is there likely to be on the world market? Also, does that perhaps provide an opportunity for progressive utilities, such as his own, to address the plutonium question as an essential nuclear power issue by making proliferation risks manageable and ensuring that they are being effectively managed? If there were to be too much uranium available then plutonium would be uneconomical for any and all nations that utilize nuclear energy. I would cite Taiwan and Japan as two examples that are heavily dependent on outside sources of energy. Plutonium recycle makes no economic sense at all. It is time that the American utilities, that have no direct stake in the matter, could perhaps further enlighten the world community on this subject, and eliminate one of the great disadvantages of nuclear power in terms of its public acceptance. It is insanity to continue with the strategy of recycling this material although there is no need for it.

Mr. Mason Willrich (Pacific Gas & Electric Enterprise):

I do not think that the extent to which additional reactors are shut down or ordered, or have their lives extended inside the United States is going to affect, in any measurable way, the uranium resource issue that you raise. The other question concerns the role of the American utility industry in the whole area of nuclear arms control and weapon proliferation risks. I have felt for decades that the U.S. electric utility ought to be much more forthright in terms of taking a leadership position in favor of managing the weapon proliferation risks.

On the other point about plutonium recycle in Europe and Japan, I think that it is a bit of an escape from reality. I prefer to work around, within and to manage effectively the diverse proliferation control programs that are operating around the world. I do not think that it would be useful to go back to the more strident forms of nuclear materials policy that was advocated during the Carter administration, comparing to what my reading of the Clinton administration policy regarding plutonium recycle efforts in countries outside the United States. I certainly would not advocate plutonium recycle inside the United States at this stage.

Finally, concerning natural gas, I do not see any enormous virtue in keeping natural gas in the ground, if it can be very effectively extracted to provide economical energy for the country, energy for transportation and energy for power generation. The current technology for using natural gas in power generation is improving, and is certainly more efficient than it was. The combined cycle technology's problem today is that of how to make it more efficient, with further improvements in turbine technology. Secondly, the natural gas resource base in North America is a very interesting proposition. For the first time we are bringing supply and demand into some form of balance. This is a market-determined balance rather than a set of prices that have been governmentally mandated. I look forward to seeing how that market will work in terms of sustaining a basic resource base. The projections of those who are closest to it indicate this country has a strong base of natural gas resources. So, I certainly will not rule out natural gas for power generation. Such generation is not being done by utilities; rather, it is being done primarily by independent power providers.

Prof. Michael Golay (MIT):

We might also note the abundant supply of natural gas is an important factor in decision making in Europe as well.

U.S. Government Employee:

The government is in the business of doing what private industry cannot do, which is looking to the future. There is a certain risk in looking too much into the future as the recent debate in Congress over the Super-conducting Super Collider (SSC) indicates. The DOE's budget proposal for the LMR was/is to do the research needed to determine whether the actinide recycle system, which is underway at Argonne National Laboratory, is technically and, most importantly, economically reasonable. Actually, we at the DOE did not propose any work on the LMR, but rather on the pyroprocessing system. We wanted to learn whether it offers potential 20-30 years from now as an alternative to existing reprocessing systems, which are all now outside the U.S. This is an important question which should be answered. That is the purpose of research, and that is what we were proposing to do.

Academic Socio-Technological Scholar:

I think there is a dangerous tendency in our attempts to separate civilian nuclear energy from nuclear energy for military purposes. Some argue that the civilian nuclear power industry, including the utilities, must survive on their own merits on a purely microeconomic competitive return-on-investment basis. I think that, if we implement such policy fully, as we have not done to-date, the United States will inevitably lose the international competition in nuclear technology. This is because the 80% of the world market for nuclear energy and nuclear power in other countries is very heavily subsidized by governments in order to fulfill dual use for national security as well as for energy security requirements. So, when we are taking a truly comprehensive macroeconomic look at our investment in nuclear energy and at the costs, and the return on those costs, it seems unfair to me to tax the American nuclear industry with having to compete with other countries' nuclear industries that are heavily subsidized by their governments.

A more accurate and realistic way of accounting for the costs of both R&D, for new developments and for current operations, is to sum up the utility costs and the civilian commercial costs, including those of R&D, and to export to the military the political costs of such items as weapons regulation and arms control. These should specifically include the costs of counter-proliferation measures and plutonium reprocessing. These are considered in the larger context of overall international security costs. As we all know, these are highly interactive with the rest of the world. So, there are only two long-range policies that are viable for the United States. They are to continue trying to maintain a modest continued government investment in this industry in order to maintain our overall security leadership; or to get worldwide nuclear weapons abandonment.

International Energy Researcher:

I am with the International Atomic Energy Agency (IAEA). I would like to draw your attention to the facts of the stature of the United States as a nation, and that it has about one-quarter of the world nuclear power reactors. The IAEA, of course, speaks for all the world on nuclear affairs. Recalling what Prof. Golay said this morning, we may have to increase significantly the use of nuclear power if we want to do something against the Earth's global warming. I am well aware that the last answer on global warming, of how much pollution the atmosphere can absorb, is not yet known. However, by the time we know the answer, it may be too late. In order to be prepared, we have to examine the situation seriously. A few years ago we might have said that we have to install about ten times as much nuclear capacity as we have now by the middle of the next century. However, while we are preparing, we can always call everything off in ten or twenty years, if one should see that perhaps that many reactors are not needed. However, we may need nuclear power, so, we have to be prepared for this possibility.

Therefore, it is important with something like 110 reactors in the United States, that we cannot let them die. In the United States you may face the possibility that maybe 25 plants which are now running will be taken out of service prematurely. The outside world will not understand this. The energy price level in the U.S. is very low compared to that of European energy. You get gas and coal very cheaply here. Your natural gas is very cheap—everything is cheap. Therefore, I probably can understand what the American utilities are doing, and their attitude that it is not up to them to solve the problems of nuclear power.

It is also not up to them to solve the non-proliferation problems. The non-proliferation issue must be addressed at the political level. It cannot be fixed by technical means alone, by special reactors. If we were to develop new reactors now and leave the utilities with the old reactors, where would the money for the new reactors come from? The money for future reactors must come from the utilities, and not from the government. You can not leave the utilities with a few old reactors that nobody wants. We now develop paper reactors. I wonder when we will switch to developing these real reactors?

Internationally, it has always been said that the last responsibility for the safe operation of the nuclear power plants is the utilities'. Then, what is this proposal which Dr. Kadak mentioned of using managing agents. Is this a special division in the utilities today, or perhaps somebody new? The utilities have experience, but are not a managing agency. Also, under this arrangement, what responsibility would that managing agency have for assuring safe operations?

Dr. Andrew Kadak (Yankee Atomic Electric Co.):

Let me answer that. The first responsibility of the safety of a power plant is that of the utility. Now, the managing agent concept is something where the words are relatively new but the practice is not. When the Yankee Rowe nuclear power plant was built in the 1950s, it was owned by ten utility companies. Those companies collectively decided that they did not understand nuclear power, themselves. Instead they decided to create a new company called Yankee Atomic Electric Company. They told that company: "you staff the plant, you train the staff, you run the plant, you maintain this nuclear power plant." In that sense we, the Yankee Atomic Electric Company, are in fact the managing agent of the owner utilities. We have the responsibility to run and operate that plant. We have no other interest except that particular plant or that particular industry. This concept is also being used as independent power producers (IPPs) are being built. These gas-fired, combined-cycle plants are owned in many ways. Some are owned by utilities who will say that they do not want to be bothered with plant operations. Instead, the utilities will subcontract to a group of people to run their power plant, saying that all that they want are electrical energy and a previously agreed-upon price. If the operator can generate energy at a better price, the operator can make and keep the money. That is the concept.

This morning I was troubled by the apparent linkage of the civilian utilities and nuclear weapons. This is not the role and the responsibility of the utilities. Dr. Willrich has just said that the utilities should be in the forefront of managing weapons proliferation. I just do not see that as our role at all. Let me give you a personal story. When I was a student at this institution [MIT], I decided deliberately not to go into the weapons business. I decided, as a nuclear engineer, to go into the commercial nuclear power industry. Whether the basis of this decision was political or philosophical, it was a career direction decision. As I go around talking to people, and I have talked to thousands of people; when they look at a nuclear power plant, their concern in not relative to the proliferation issues, rather, it is a concern about health, and power plant safety and accident risks. It has been very rare that I would encounter someone saying they were sorry but my plant is a proliferation risk and, therefore, it should be shut down.

I can understand the positions of various people here at this Conference on this issue. However, to try to bring nuclear weapons and the commercial nuclear industry together, at least as we know it in the U.S., as a means of controlling nuclear weapons would be a very inappropriate application of our expertise. Nuclear weapons are irrelevant to the questions of why nuclear power should or should not exist. I am concerned about the tyranny of a technical elite in prescribing this. I have used the word tyranny, and I mean it. I think that the nuclear critics are out of touch with the people on this one.

U.S. Nuclear Power Industry Professional:

I was pleased that the last questions have gotten us back to the theme of this session, that of how long will nuclear power play a role. In particular, I support comments of the two authors on the need for power and that economics will provide the answer. I am somewhat surprised that, so far in this Conference, we have not really focused on the regulatory process within the U.S. Typically, when things go sour, we fall into the mode of always trying to point the finger of blame at other individuals. When we look at the comparisons between our international nuclear partners and the U.S., we see major differences in the regulatory schemes. Dr. Willrich observed concerning compliance with the regulations that one needs to look at the regulatory process to see that, in the U.S., we really are not dealing with an issue of compliance within the regulatory system. Rather, in my view, we are dealing with safety perceptions and issues of how to deal with ever-decreasing increments of risk. This is the case if one looks from the start of the Atomic Energy Commission to the present. With early 1993 regulations the actual legal requirements that the utility has to satisfy every day in operating its plant, there are more than 4,000 regulatory guides that constitute informal requirements. Legally they are not required to be met. However, when one examines the increases in cost and staffing, as Dr. Kadak illustrated, one can see that they increase along with the increases in the number of these informal regulatory requirements. I submit that among the problems of the future operation of nuclear power plants are not only those of trust and confidence from the public, but those of these accumulated regulations.

I submit that we in the nuclear industry still lack the trust and confidence of the public. I also submit that the public lacks trust and confidence in the regulator, in its own rules and regulations, and in the claim that we have set an adequate level of protection for public health safety.

Concerning staffing in the utility industry, we tend to focus on the idea that the way we are going to reduce the costs in the U.S. nuclear plants is to reduce staffing. I submit that we need to look at this policy in a much larger context. If one analyzes the data over the last several years, one can see a $35M/yr/unit gap in performance between the top and bottom performing plants in terms of costs; in terms of the average over the past three years within the U.S. plants. Of one analyzes further, one finds that there is no correlation of costs with plant age or with reactor type. In fact, the explanation comes down to something more basic, and it is not just due to staff size.

You could formulate a rule of thumb that the amount of $1M/KW-hr that you can reduce in costs for a typical reactor is about eight full power operational days, more than about 50 people. One sees very rapidly that one cannot reduce enough to narrow this $35M/unit gap simply by shrinking the staff size. This is because it will be necessary to reduce the staff by more people than are already there. So, you need to look at this whole issue of the economics for generation costs, O&M costs and capital costs, and examine how one can operate these plants in a competitive environment against other sources of generation. The competition, as we all know, is not from the other nuclear plants; it is from the alternative technologies.

Prof. Golay:

I wish to build upon the mention of regulation as a cost factor, especially in the U.S. It has not been said, but I think is widely recognized by those here, that an important aspect of both economic and safety regulations is the nexus with political conflict. This intersection arises by virtue of the lack of alternative forums within the United States' political system at which broad social policies regarding the acceptability of nuclear power could be played out. Much of this conflict becomes focused on specific licensing and price-setting issues in the economic and safety regulatory arena. For the U.S. and other countries, this feature makes their decision-making much more complicated and uncertain; and ends up providing a disincentive for the use of regulated technologies. Germany provides another example where that sort of regulatory disincentive mechanism works strongly.

SESSION THREE

CAN NUCLEAR POWER GAIN PUBLIC ACCEPTANCE?

Roger Kasperson

Clark University

RESPONSE:

FEAR, IMAGE, AND VALUES

Thomas Hughes

University of Pennsylvania

INTRODUCTION

Session 3 – Can Nuclear Power Gain Public Acceptance?

In the United States nuclear power is a topic concerning which a well-informed person must have an opinion. This fact is a symptom if the controversy which has surrounded the topic of nuclear power for the past three decades. This controversy is strong in most countries, and is widely cited as the main reason that few new nuclear power plants are being built outside of eastern Asia.

Literally, this controversy is important to a nuclear power plant owner not because the plant may be unpopular; but rather because it can make all aspects of the plant's life more expensive. Such expenses are uncertain, but can potentially be ruinous, as with the examples of the Seabrook and Shoreham stations. To this point the economics of nuclear power have been competitive in many locations. However, the potential that the costs of a plant could become uncontrolled has been enough to motivate cancellation of new plant projects and premature shutdown of operating plants.

Matters do not always operate this way. For example in Japan nuclear power is controversial, but it has not been seriously affected economically by this fact. It is necessary for the citizens to be able to interfere with a plant's design, constriction or operational schedule in order to inflict serious financial pain. The political and regulatory systems of different countries offer differing freedom for such interference. Among countries using nuclear power the system of the United States offers the most access, and those of France and Japan, the least. Not accidentally, nuclear power technology has been used with greater success in the latter two countries.

Because public acceptance is so important in most countries to the success of nuclear power projects, gaining it has been a primary objective of many reactor concepts proposed during the past 15 years. This usually has been done by trying to design the plant so that it could either make core damage very unlikely or survive a severe accident, without the need to evacuate the surrounding population. A problem with thesis strategy is that demonstrating that the concept will work as promised requires that authority figures certify this to be true. With the loss of legitimacy which authority figures and institutions suffered during the Vietnam war years such assertions are often less convincing than they used to be. So far, they have been insufficient to garner acceptance for new reactor concepts.

Other factors which have been asserted to explain public anxiety about nuclear power include distrust of the people and organizations using nuclear technologies, anxiety and fear arising from the existence of nuclear weapons, fear of reactor accidents and distrust that nuclear waste disposal will be accomplished successfully. The roles of these and other factors in shaping attitudes about nuclear power will differ among individuals, and will probably never be explained completely. However, their overall importance is hard to deny.

Finally, it has been noted that in most developed countries society does not view nuclear power as providing high benefits. Like other technologies, it produces electricity, which, while valuable, is ordinary. It has been suggested that until nuclear power is thought to be valuable for some other reason it will remain unappreciated, with few people willing to tolerate its risks. Saving the plant from global warming or reducing dependence upon imported fuels have been mentioned as potentially important reasons that nuclear power might be considered to be more beneficial in the future. We shall have to wait to see.

Because understanding the factors and arguments explaining public acceptance (or its lack) are so important a session on this topic in the Conference is essential. However, this session was organized around speakers who are students to technological development, rather than around advocates for or against nuclear power.

CAN NUCLEAR POWER GAIN PUBLIC ACCEPTANCE?

Roger Kasperson

After several decades of vigorous and initially successful development, nuclear energy for commercial production of electricity is in stalemate in the United States. A changing world energy situation has dampened demand and led to declining oil prices, while the long-term prospects for petroleum suggest it is a transitional energy source. The concern of environmentalists over nuclear power, at first limited to several advanced industrial societies, has spread throughout developed and developing countries alike. The accidents at Three Mile Island in 1979 and Chernobyl in 1986 stimulated widespread soul-searching over safety programs, and exacerbated public concerns over nuclear risks in a number of countries. Poorly designed and socially insensitive programs for radioactive waste disposal have resulted in strong public opposition to waste facility siting and reinforced public doubts over the long-term isolation of such wastes and the ultimate impacts on future generations. The revelation of radioactive contamination of workers, publics, and the environment in the wake of the dismantling of the Soviet empire have generated fresh concerns over the worldwide dissemination of nuclear technology. Taken together, these events and surprises question whether this technology, whatever the innovations in technical design, can overcome a history of errors and mismanagement to win confidence for a new beginning.

Meanwhile, the recent history of nuclear energy has left a variable imprint and legacy throughout advanced industrial societies. Some countries, such as Norway and Denmark, have decided against the development of nuclear programs. Austria and the Netherlands have made national decisions to limit or delay the further development of nuclear power. The United States, the United Kingdom, and (perhaps) West Germany face de facto moratoria on nuclear power, the products of economic forces, widespread public opposition, and failure to solve the waste disposal problem. France, Japan, and Canada continue to press ahead, but with heightened uncertainty concerning the eventual outcome of the national programs.

Some see in this situation closure to two decades of debate, with a clear-cut "victory" of opponents over nuclear power advocates; other see the seeds for a "second era" of nuclear development and a new future for nuclear power (Weinberg 1981; Weinberg 1982). A common view among environmentalists is that the "war" over nuclear power is over, with little prospect that the technology can rise from the ashes. What is clear is that the present hiatus in nuclear energy development provides an opportunity to rethink the technology, management structures, and technological paths. Current deliberations on "passive" and "semi-passive" safety systems, on international emergency response and communications, and the formulation of effective programs for radioactive waste management are useful steps in this direction. And yet the prospect for a socially acceptable future for nuclear power appears elusive, with significant doubts that anything short of a clean break from the past in technology, management, and institutions, with a large dash of good luck thrown in, will suffice for a new beginning.

The paper addresses four major objectives:

- to characterize briefly how nuclear power lost public confidence;
- to explore the major sources of the public acceptance problem;
- to examine whether increased information and education is the answer;
- to identify prospective pathways for increased public acceptance.

HOW DID NUCLEAR POWER LOSE ITS PUBLIC MANDATE?

Public attitudes to the civilian uses of nuclear energy in the United States generally focused on the large potential benefits of the technology, especially for economic growth, low-cost electricity, and improved human welfare. There was little concern prior to the late 1950s about the risks posed by the few reactors in operation, and pollsters did not even bother to survey public opinion. While considerable public concern existed over the development of nuclear weapons and the fallout of radioactivity from the testing of such weapons (Erskine, 1963; Kopp, 1979), nuclear power risks received less media attention and public scrutiny.

The nuclear industry in the United States grew rapidly during the 1960s—by 1968 there were 14 plants in operation and another 39 under construction, while the size of plants increased from the 90 MWe of the first plant to reactors 8-10 times that size. With this growth came scattered public protests against the siting of plants (as at Bodega Head in 1961 and at the proposed Ravenswood plant in the Queens area of New York City in 1962-63). Nevertheless, the early opinion polls indicated broad public support, with less than one-fourth of the public opposed to nuclear power (Mazur, 1981).

With the emergence of the environmental movement in the late 1960s, new opposition to the expansion of nuclear power appeared. At first the focus was upon the possible adverse environmental impacts of nuclear plants (such as thermal pollution), and in 1970 a federal court required that the Atomic Energy Commission take account of environmental impacts in decisions on plant licensing. Nonetheless, public response to nuclear power in the period between 1970-1974 in public opinion polls showed consistent two-to-one majorities in favor of nuclear power.

Between 1975 and 1979, a majority of the American public continued to support nuclear power, but at reduced levels (Figure 3.1). A number of events contributed to growing ambivalence in public sentiment. In 1975, a fire at the Browns Ferry plant in Alabama disabled the plant s safety systems and led to some loss of core coolant (U.S. Office of Technology Assessment, 1984, 213). A year later, seven states held referenda on nuclear moratoria and, although all were defeated, they brought nuclear safety issues to a broad spectrum of the public. In 1979, the accident at Three Mile Island set off a national soul-searching concerning nuclear power, especially over the credibility of claims of the impossibility or remote possibility of a serious accident leading to a core melt, and majority support for nuclear power was lost. A period of temporary public reconsideration occurred between 1979 and 1981; since that time majority opposition to nuclear power in the United States has been clearly apparent. This public opposition is even more decisive when the issue moves from the national to the local level (i.e., would you support the construction of a nuclear plant in your community?).

By 1987, public opposition to expanding nuclear power reached a 4-1 plurality (Nealey, 1990), and a Cambridge Energy Research Associates (1990) poll revealed that about 75% of respondents viewed nuclear energy as the most dangerous way to generate electricity.

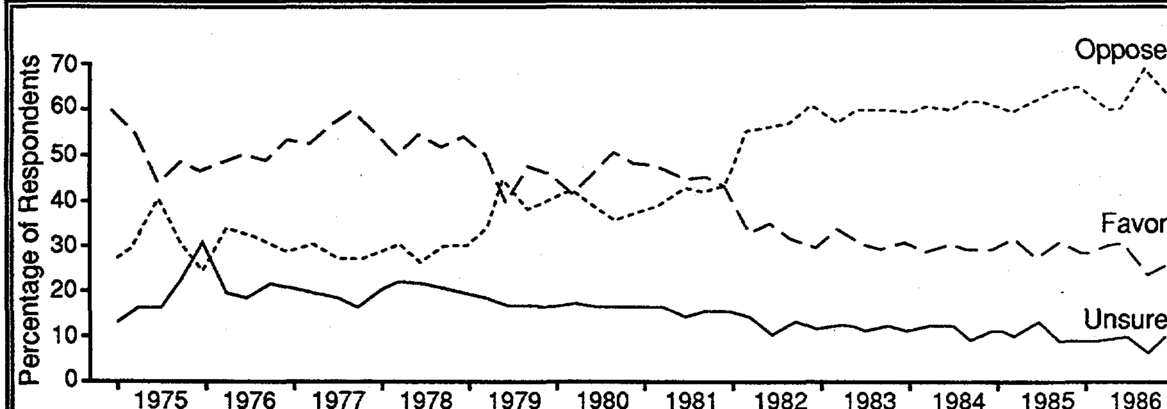

Figure 3.1: Public Attitudes To Nuclear Power In U.S.

NOTE: "Don't Knows" are unsolicited responses as this category is not given as a response option.

Source: Cambridge Reports.

Underlying this erosion of public support for nuclear power during the 1980s were concerns over (1) the lack of progress on "solving" the nuclear waste disposal problem, (2) reactor safety, and (3) a management and institutional system seemingly more committed to protecting the nuclear industry than the public. A particular problem is that Americans apparently no longer believe that the benefits of nuclear power justify the risks involved. Indeed, only 18% of the U.S. public believed in 1988 that the benefits strongly exceeded the risks (Table 3.1). On the other hand public ambivalence is also apparent since large majorities also oppose shutting down existing plants (Nealey, 1990, 4). A 1991 Gallup Poll found, for example, 52% of the U.S. public opposed to building more nuclear plants but more respondents (40%) citing nuclear as a needed future energy source than any other (Time, April 29, 1991). Similarly, a 1992 national poll by Environmental Research Associates found that 67% of both children and teens interviewed and their parents viewed nuclear energy as either "very" or "somewhat" important for meeting the country's energy needs (U.S. Council for Energy Awareness, 1992).

In other countries, the public response is more variable although public concern over nuclear plant risks and nuclear waste disposal is apparent in most. The results of identical polls in the 10 countries of the European community in 1982 revealed that West Europeans, even prior to the Chernobyl accident, were deeply divided (38% in favor; 37% opposed) on whether or not nuclear energy should be developed (Riffault, 1983). Opinions were solicited on two arguments—the economic argument that the failure to develop nuclear power would lead to cutbacks in electricity consumption, and the safety argument that measures at nuclear power plants had eliminated nearly all danger. Only in France did majority support exist for both the economic and safety arguments.

Table 3.1

Public Attitudes Toward Nuclear Power, 1988

	Benefits strongly exceed risks	Benefits only slightly exceed risks	Risks only slightly exceed benefits	Risks strongly exceed benefits	About the same or do not know	N
Nuclear power						
Total public	18	23	17	30	12	2,041
Men	23	26	15	28	8	958
Women	13	20	18	32	16	1,083
18 to 24	12	23	28	30	7	318
25 to 34	16	24	19	33	7	486
35 to 44	14	22	18	34	12	373
45 to 64	24	23	13	26	15	532
65 and older	21	23	8	29	19	332
Less than H.S. graduate	15	25	18	25	18	530
H.S. graduate or some college	18	22	17	33	11	1,155
College graduate	22	23	14	32	9	356

Source: National Science Board. 1990. *Science and engineering indicators, 1989.* Washington: National Science Foundation, p. 400.

Chernobyl was a major shock and produced much rethinking of nuclear power. Other events, such as the TransNuclear affair, have also been important. The bulge of public opposition following the Chernobyl accident has ameliorated over time. In France, for example, a 1989 SOFRES poll revealed that 67% of the French public subscribed to a compromise position on nuclear power in which no new nuclear plants would be built but existing plants should continue to operate (Chaussade, 1990), a view similar to that in the United States. Similar sentiment has also been apparent in Germany and Sweden. In France, a 1990 poll found 54% of males and 45% of females in favor of "a new civil nuclear energy development in France" if the cost of oil were to rise sharply (Hastings and Hastings, 1992, 93). This qualified support may not be sufficient for embarking on the next generation of nuclear power but suggests that some public assets exist for possible increased future public acceptance of nuclear technology amidst the evident problems.

SOURCES OF THE PUBLIC ACCEPTANCE PROBLEM

It is apparent that the sources of public concern over nuclear energy are multiple; no single factor explains the substantial public distrust of this technology that exists in most countries. The substantial accumulation of research on this subject, however, has identified a number of key dimensions that operate across societies.

The Nature Of The Hazards

Experts and members of the general public, as we now know quite well, judge the risks[1] of nuclear power differently. In studies conducted at Decision Research, Inc. in the United States (Slovic, Fischhoff and Lichtenstein, 1982), respondents have judged the risks of nuclear power to be as almost as great as those posed by automobile accidents (38,000-50,000 fatalities per year in the U.S. in recent years). A similar study of responses of 700 adult men and women in the greater Rotterdam harbor area of the Netherlands to 26 risky activities revealed that respondents judged nuclear power as more risky than most other activities and technologies, including drunk driving, chlorine transport, and dangerous occupations (Vlek and Stallen, 1981, 248). Even in a West German study where nuclear power was judged only eighth among some 13 hazards, it still was seen as more risky than coal, pesticides, and X-rays (Renn, 1981, 139). In France, a similar study found that respondents rated nuclear power, along with narcotics, tobacco, alcohol, and motorcycles, as one of the most dangerous activities (Moatti, Stemmelen and Fagnani, 1984). These public perceptions depart widely from technical risk assessments that have generally estimated relatively low levels of public health risk, primarily because of the low risk from normal operations and the low probabilities of a major accident leading to an off-site release.

The public assessment of high risk is, in part, a product of the difficulty that non-experts have in judging low probabilities. The Decision Research studies show that, whereas members of the public perform quite well in ordering risks from large to small, they tend systematically to overestimate low-probability events, particularly if they are potentially catastrophic and well publicized (Slovic, Fischhoff and Lichtenstein, 1982). Similarly, they tend to underestimate chronic diseases that occur with high frequency and that are not associated with many fatalities at a given event (Figure 3.2). In this sense, major accidents, such as those at Chernobyl and Three Mile Island, with the enormous media coverage that occurs, almost certainly contribute to high public estimates of the probability of major accidents and concern over the geographical scope of potential consequences.

But other attributes of nuclear power risks enter in as well. Taxonomic research on technological hazards (Hohenemser, Kates and Slovic, 1983), based on some 12 biophysical "descriptors" of hazards, reveals that nuclear power scores high on many of them and is in a small class of "multiple extreme" hazards. Since the taxonomy predicts rather well public

[1] As used in this paper, "risk" refers to the probability of harm to people or things they value as measured over some unit of time or use.

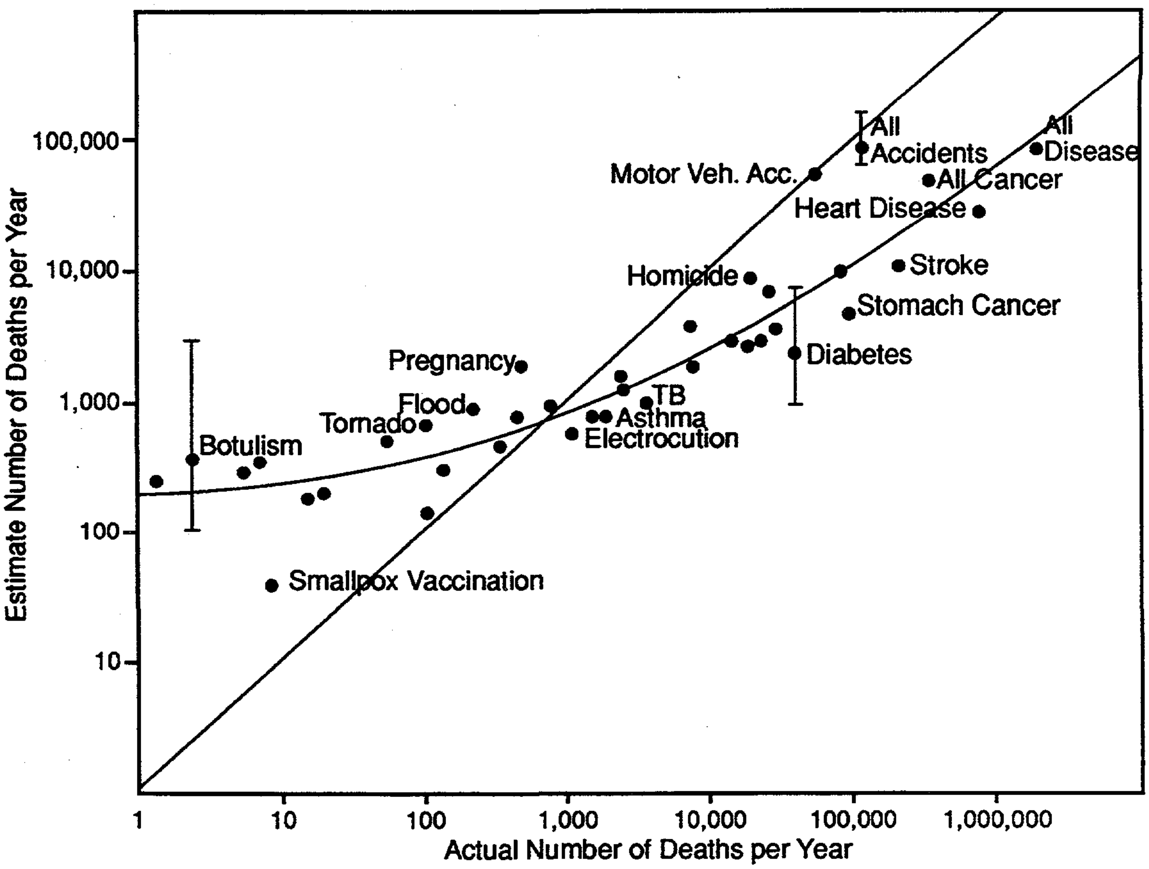

Figure 3.2: Relation Between Judged Frequency And The Actual Number Of Deaths Per Year For 41 Causes Of Death.

NOTE: Respondents were told that about 50,000 per year die from motor vehicle accidents. If judged and actual frequencies were equal, the data would fall on the straight line. The points and the curve fitted to them represent the averaged responses of a large number of lay people. While people were approximately accurate, their judgments were systematically distorted. To give an idea of the degree of agreement among subjects, vertical bars are drawn to depict the 25th and 75th percentile of individual judgment for botulism, diabetes, and all accidents. Fifty percent of all judgments fall between these limits. The range of responses for the other 37 causes of death was similar.

Source: Slovic, Fischhoff and Lichtenstein, 1982, p. 144.

concern over technology, it is apparent that the qualitative attributes of hazards may go far in explaining the differing judgments between experts and members of the public over the acceptability of technologies. It also suggests that publics are probably quite "rational" in their assessment of nuclear power, but that the rationality is different from that of technical experts.

Key among such attributes is the catastrophic potential of nuclear power. In an experiment at Decision Research, respondents were asked to estimate the frequency of death to be expected from some 30 activities and technologies. They were also asked to indicate how many times more deaths than the average would occur if next year were "particularly disastrous" for the technology or activity considered. While the expected fatalities from nuclear power in an average year were fewer than those for any other activity or technology, in the worst year they were much greater than for any other technology (Table 3.2). In fact, more than 40% of the

Table 3.2

Fatality Estimates and Disaster Multipliers for 30 Activities and Technologies

Activity of Technology		Geometric Mean Fatality Estimate Average Year		Geometric Mean Multiplier Disastrous Year	
		League of Women Voters Sample	University Student Sample	League of Women Voters Sample	University Student Sample
1.	Alcoholic beverages	12,000	2,600	1.9	1.4
2.	Bicycles	910	420	1.8	1.4
3.	Commercial aviation	250	650	3.0	1.5
4.	Contraceptives	180	120	2.1	1.4
5.	Electric power	660	500	1.9	2.4
6.	Fire Fighting	220	390	2.3	2.2
7.	Food coloring	38	33	3.5	1.4
8.	Food preservatives	61	63	3.9	1.7
9.	General aviation	550	650	2.6	2.0
10.	Handguns	3,000	1,900	2.6	2.0
11.	H.S. and college football	39	40	1.9	1.4
12.	Home appliances	200	240	1.6	1.3
13.	Hunting	350	410	1.6	1.7
14.	Large construction	400	370	2.1	1.4
15.	Motorcycles	1,600	1,600	1.8	1.6
16.	Motor vehicles	28,000	10,500	1.6	1.6
17.	Mountain climbing	50	70	1.9	1.4
18.	Nuclear power	20	27	107.1	87.6
19.	Pesticides	140	84	9.3	2.4
20.	Power movers	40	33	1.6	1.3
21.	Police work	460	390	2.1	1.9
22.	Prescription antibiotics	160	290	2.3	1.6
23.	Railroads	190	210	3.2	1.6
24.	Skiing	55	72	1.9	1.6
25.	Smoking	6,500	2,400	1.9	2.0
26.	Spray cans	56	36	3.7	2.4
27.	Surgery	2,500	900	1.5	1.6
28.	Swimming	930	370	1.6	1.7
29.	Vaccinations	65	52	2.1	1.6
30.	X-rays	90	40	2.7	1.6

Source: Slovic, 1980.

respondents presented multipliers for nuclear power that were greater than 1,000. A replication of this experiment in West Germany produced similar results, with an average multiplier of 6971 (Renn, 1981, 139).

In another experiment, a new group of 28 students was asked to write scenarios of the maximum credible disaster that might be produced during their lifetimes by a nuclear power plant. One-third of the scenarios postulated an explosion within the reactor and an expected number of fatalities several order of magnitude greater than the worst case estimated in the U.S. *Reactor Safety Study* of 45,000 early illnesses and 1,500 latent cancer fatalities per year for a 10-40 year period, with a probability of 10^{-9} per reactor year (U.S. Nuclear Regulatory Commission, 1975, I, P. 83). Three respondents wrote scenarios postulating worldwide radioactive contamination and death.

These research results emerging from studies conducted in the U.S. and West Germany, while based on limited samples, suggest that members of the public expect nuclear power to lead eventually to immense disasters. Accidents such as Chernobyl, recent revelations of large scale contamination in the former Soviet Union and East Germany, and the magnitude of the U.S. defense waste cleanup can only add to this spectre of immense nuclear disasters and environmental catastrophes.

Fear

The birth of nuclear energy in weapons of destruction has provided a lasting legacy of deep-seated public fears. The link between nuclear energy and weapons has been a frequent theme in literature and films, as Weart (1988, 1991) has so effectively shown. Perhaps the first novel to treat this issue was H.G. Wells' *The World Set Free* (1914) which portrays a cataclysmic world war during the 1950s in which cities are left uninhabitable by induced-radioactivity bombs the size of a handbag. John Hersey's widely read factual account, *Hiroshima*, describes in detail the death and destruction caused by an atomic bomb. A wave of horror movies in the United States during the 1950s featured monster creatures created or awakened by nuclear weapons: *The Beast from Twenty Thousand Fathoms* (1953) assaults New York City; in *Them* (1954), monster ants invade Los Angeles; and *Godzilla* (1955) destroys Tokyo. In 1959 the film based on Nevil Shute's novel *On the Beach* portrayed the end of humanity as a result of worldwide nuclear war. Popular books such as *We Almost Lost Detroit* (Fuller, 1975) and *The Prometheus Crisis* (Scortia and Robinson, 1975), and films such as *The China Syndrome* have presented vivid accounts of reactor accidents and meltdowns.

Experience since World War II has provided credence to the spectre portrayed by these films and novels. Civil defense drills, commonplace in the U.S. during the 1950s, had school children fall to the floor and cover their heads. A national program of underground shelters is currently part of the Swiss experience. The Cuban missile crisis of 1962 made the prospect of global nuclear war even more vivid, and fifteen years later a national poll found 4 of 5 Americans convinced that if too many countries acquired a nuclear capability, "some irresponsible country is bound to set off a bomb that could blow up the earth in World War III" (deBoer, 1977, 407-408). The Israeli bombing of Iraq's reactor in 1981 raised concern over military attacks on nuclear plants, and the growth of terrorism and the resumption of the arms race during the 1980s certainly contributed to public fears over nuclear destruction during that decade of growing public opposition.

This history, it has been argued, nourishes fear over nuclear energy. Pahner (1976) argues, for example, that a substantial part of the public concern over nuclear power plants represents anxiety "displaced" from the fear of nuclear weapons. Such fear, in Pahner's view, stems from (a) preexisting images of the horror of nuclear war, (b) conscious and unconscious fears of the immediate and long-term effects of radiation on genetic processes. Similarly, Robert Lifton (1967, 1979) argues that the development of nuclear weapons has evoked the image of the extermination of the human species with its own technology. The fear that nuclear weapons may be used during the course of one's life evokes the idea of total biological destruction, of the possible interruption of all human continuity. Such interpretations find support in the studies noted above which reveal public perceptions of great catastrophes associated with nuclear plant accidents, with the consistent findings of polls in many countries that nuclear power plants can "explode" like nuclear bombs (and "cause a mushroom-shaped cloud like the one at Hiroshima") (U.S. Council on Environmental Quality, 1980), and the public tendency to cite the wide variety of risks connected with nuclear energy in free association tests (Hensler and Hensler, 1979; Renn, 1981, 250).

Perception Of Benefits

Although the acceptability of nuclear energy is certainly far more complex than that suggested by a simple weighing of costs and benefits, it is clear that the perception of substantial economic benefits of any technology is an important ingredient for public tolerance of the risks and supportive public policy. Since Chauncey Starr's (1969) seminal article on risk comparison, it has been clear that riskier activities and technologies are more likely to be tolerated (if not accepted) if the benefits are correspondingly larger. Perhaps the striking difference between the evolution of French and American public opinion over the past decade noted above is the widespread public judgment in France that nuclear energy is a corner stone to French energy independence, to economic growth, and to French international independence and prestige. In the United States (and in many other countries), it is unclear that the recent losses of public support lie in radically different assessments of risk (although increasing concern over some of the risks—and particularly waste disposal—has been evident). Rather, it may be the change in perception of benefits that has been the undoing of nuclear power.

From the start, nuclear energy has been viewed as a risky technology. Indeed, Weart (1991, 33) refers to the "crossroads" imagery of nuclear power, with one road leading to atomic destruction and the other to the atomic "golden age," that has existed even prior to Hiroshima. What has changed fundamentally is the belief in the economic promise of nuclear energy—the technology which, it was promised in the 1950s, would result in a human race "with . . . little need to earn its bread by the sweat of its brow . . . such a race could transform a desert continent, thaw the frozen poles, and make the whole world one smiling Garden of Eden" (Weart, 1991, 32). The falloff in energy demand in many industrial societies, the increased use of conservation, and the precipitous decline in the prices of world petroleum during the mid-1980s, when joined with the escalating prices of nuclear-generated electricity in many countries, have led to substantial changes in the public's assessment of nuclear benefits. Nuclear power is, bluntly, seen increasingly as "not worth" the risks.

Benefit perception has been relatively neglected in social science research so that only sketchy evidence is available. As noted above, the perceived economic benefits of nuclear power fell between 1978 and 1982 in six of the nine European countries treated and only in France did favorable ratings exceed 39% of the respondents. In the United States, a Resources for the Future Survey in 1980 found that nuclear power stood at the bottom of the public's list of preferred energy sources and the clear choice for least governmental effort (U.S. Council on Environmental Quality, 1980, 22), but the roles played by perceived risk and benefits were unclear. Slovic (1980) and colleagues found that respondents in their experiments rated the benefits of nuclear power at a small fraction of those of electric power, contributing to the judged unacceptability of nuclear power risks. In an earlier study of public attitudes in Austria, Otway, Maurer, and Thomas (1978) found that a perception of strong economic and technical benefits (rather than low risks) contributed to most of the support of proponents. In his participatory cell planning experiments in West Germany, Renn (1985) found that the benefits of long-lasting supplies of uranium and inexpensive electricity explained the slightly positive commitment to nuclear energy, but observed that if this perceived economic superiority were to be challenged, "support for nuclear energy could collapse rapidly" (p. 127). Also, interestingly, beliefs about the benefits of nuclear power appeared to be relatively independent from beliefs about risks. A more recent 1988 national poll in Germany found only 26% of the public who believed that the advantages of nuclear power outweighed the disadvantages; meanwhile a 1991 British poll found that only 36% of respondents viewed nuclear power as mostly beneficial and 49% as mostly damaging (Hastings and Hastings, 1993, 93-94). Clearly, the public judgment of nuclear energy benefits is an issue about which more needs to be known.

Value Conflict And Cultural Setting

It is not surprising that a technology first used in weapons has been the subject of intense debates involving value questions from the very beginning. The scientists who built the bombs, for example, persuaded the U.S. government to argue at the newly founded United Nations that nuclear technology was so dangerous that international ownership of is should be instituted. They also were influential in establishing "civilian" control of the technology. The early arguments for nuclear power stressed positive values—that the technology would reduce the price of electricity everywhere (and particularly in the poor nations), promote general welfare through economic growth, and help liberate humanity from manual labor.

More recently, nuclear opponents have introduced a succession of value challenges. Commoner (1969) emphasized the possible burdens of nuclear wastes for future generations, an issue subsequently taken up by the Sierra Club but given its most compelling expression in Weinberg's "Faustian bargain" metaphor (Weinberg, 1972). Issues of democratic process and political accountability have also received considerable attention (Green, 1975; Ebbin and Kasper, 1974).

An evaluation of the 1973-1974 congressional hearings on nuclear reactor safety in the United States showed that the controversy embraced a host of social, political, moral, and other issues about the regulation and use of technology in a democratic society (Del Sesto, 1980). Pro-nuclear advocates stressed the benefits that would accrue to human welfare through improving the standard of living, increasing the rate of economic growth, and achieving energy self-sufficiency. Nuclear opponents stressed the inequity to future generations, the dangers to civil liberties and the democratic process, and the global threat of weapons proliferation.

The presence of underlying value conflict has been confirmed by several European studies. In an analysis of 252 Dutch social and natural scientists, Stallen and Meertens (1979) found two major values operating in attitudes toward nuclear power: social and societal concern versus technical and economic concern. The more the individual favored nuclear power, the less concerned the person was about social and societal issues and the greater the value for technical and economic aspects. These findings are quite consistent with the Del Sesto results. Stallen and Thomas (1985) found differing values about health and well-being to be key features of anxiety over industrial facilities.

A somewhat different picture emerges from research in the early 1980s in France relating attitudes toward nuclear power to ideology (Brenot, et al., 1983). This analysis placed nuclear power within the context of some 76 conflictual topics (e.g., abortion, death penalty, immigration, atomic weapons, etc.). Through the use of factor analysis, major axes of social differentiation were identified, in which nuclear plants lay on a "movement"—"status quo" dimension. This axis, the authors argue, expresses the main conflict in contemporary French society that opposes traditional and conservative values against modernist and progressive ones. It also has a political and ideological (right wing/left wing) character. Meanwhile, a point on the periphery indicates that an issue is closely correlated with other nearby points. The public assessment of nuclear power, the authors conclude, is multidimensional and ideological, and ethical issues are often the "hidden" reasons for negative responses.

Yet a different approach to the ways in which values and public evaluations interact comes from anthropologists adopting a cultural interpretation of risk response. Such analyses have adopted the so-called "grid-group construct" to analyze the cultural biases that different social groups bring to risk management issues (Douglas, 1978; Rayner, 1984; Thompson, Ellis and Wildavsky, 1990). The *group* variable describes the range of social interaction within a social unit, with low-group individuals fending for themselves and high-group people dependent upon one another. The *grid* variable describes the nature of interactions within the unit, with low grid indicating an egalitarian state of affairs and high grid sets of constraining conditions. These dimensions may be used to construct a matrix of four prototype visions of social life (Figure 3.3). These visions, it is argued, make members sensitive to different aspects of technology problems and lead to different responses to the siting of controversial facilities (Cantor and Rayner 1985).

While these various analyses do not point to a common set of findings concerning the rule of values in public judgments of risk acceptability, they do provide long-term evidence that public response to nuclear power is value-laden and cultural in context. This condition has, as discussed below, far-reaching implications for efforts to win greater social acceptance of this technology.

high	**B. ATOMIZED INDIVIDUALS** Have to take what they can get, may resort to egalitarian groups for support of ignored.	**C. BUREAUCRATIC/HIERARCHICAL** Seek long-term benefits for collective disposal to promote community stability, e.g., public schools, hospitals, guaranteed trust funds, etc.
GRID		
low	**A. COMPETITIVE/MARKET** Seek immediate rewards that can be disposed of by individual households, e.g., direct payments, tax benefits, etc.	**D. EGALITARIAN GROUP** Seek community control over process. Emphasis on regulation, monitoring, and prevention of accidents rather than compensation
0	low	high GROUP

GROUP

Figure 3.3: Socio-Cultural Patterns Of Public Response To Siting Controversial Facilities.

Source: Cantor and Rayner 1985.

Institutional Credibility And Distrust

The acceptability of risk is often as much an issue of confidence in the institutions that manage the risk and the perceived fairness of the risk allocation process as the levels of risks and benefits involved (Kasperson, Golding and Tuler, 1992). The degree of trust in the guardians of nuclear safety should be expected to vary with the political culture of the respective country, so that societies with a tradition of high regard for civil servants may well find greater public confidence in safety assurances than those with traditional low regard for governmental bureaucrats. The Chernobyl accident of 1986 set off much commentary on the differences between "open" and "closed" societies in regard to provision of information on the accident and its consequences. In France and West Germany, the handling of information relating to radiation hazards led to allegations of "withholding" of information.

The extent to which public distrust can enter into the acceptance of nuclear power is quite apparent in the United States. Various public opinion polls have shown a remarkable decline over the past three decades in the confidence people have in governmental institutions, public officials, and the press. As early as 1976, a poll found that only scientists commanded "a great deal" of confidence on nuclear power issues. with the Nuclear Regulatory Commission (39%), the President of the United States (24%), the heads of electric power companies (19%), and the companies that produce equipment for nuclear power plants (12%) lagging seriously behind (Harris and Associates, 1976, 29). The long-term neglect and low priority accorded to resolving the problem of nuclear waste disposal and the contentious process of searching for sites for waste repositories have undoubtedly contributed to public distrust of responsible authorities in Europe and North America. Indeed, the lack of public confidence in the nuclear waste disposal led the U.S. Secretary of Energy to commission a special task force to consider the subject, an effort that detailed in depth the far-reaching problems entailed in the lack of public trust and confidence and the uncertainty as to whether they could be surmounted (U.S. Department of Energy, Task Force on Trust and Confidence, 1993).

The history of particular institutions may also be important. The role of the U.S. Department of Energy, for example, as the lead agency in devising a waste management program has not strengthened the federal government's credibility, as the Department of

Energy's own Task Force attested. As the inheritor of the U.S. Atomic Energy Commission's neglect of and past mistakes in waste management, the U.S. Department of Energy shoulders an unusual burden of distrust. This was underlined in earlier U.S. Office of Technology Assessment (1985) report that identified the lack of public credibility as the most serious problem facing the American radioactive waste management program. In the United Kingdom, the degree of openness and candor of the Department of Environment in the selection of low level waste repository sites has been an issue of continuing public debate. Exactly how distrust enters into attitudes towards technology and interacts with risk perception remain uncertain, although it is apparent that the *process* by which risks are allocated to others enters extensively into public judgments about the acceptability of risks.

What may be concluded from this discussion of the sources of public acceptance problem for nuclear power? First, it is apparent that there is no simple answer—the sources of public concern are multiple, are rooted in the risks and benefits associated with the technology, are associated with deep-seated levels of fear and with fundamental values and cultural perspectives, and undoubtedly vary in their combination and degree of interaction from one society to another. The linkage of public concerns with fear, underlying belief systems, and social movements also suggest that current attitudes are likely to be quite resistant to efforts aimed at changing them. Given these strong public anxieties, it is imperative that the publics have a high degree of confidence and trust in the institutions that manage the risks and protect public safety and the environment. And there is a public trust crisis with nuclear power that is anchored deeply in broader patterns of eroding trust in social institutions and (particularly) in those entrusted to manage nuclear technology and the nuclear fuel cycle.

EDUCATING THE PUBLIC—IS IT THE ANSWER?

Public concern over nuclear power, it has frequently been asserted, arises from unfounded fears, misinformation, misperceptions of risks, and "irrationality." Educational programs and improved information, in this view, are the routes to greater public acceptance (see for example, Delcoigne, 1979 and Firebaugh, 1981, but public pronouncements of nuclear advocates are full of this rhetoric). This belief has encouraged the nuclear industry in a variety of countries to wage extensive campaigns designed to counteract "misinformation," to provide a fuller understanding of nuclear risks and benefits, or to indicate why accidents that happen elsewhere would not happen in the particular country in question.

It is true, of course, that the public has only limited knowledge of nuclear power. Various surveys of public opinion have confirmed such a finding (Melber, et al., 1979); a detailed U.S. study, for example, revealed that, out of five relatively simple multiple-choice questions on nuclear power, 51% of the respondents answered no more than one of the questions correctly (Reed and Wilkes, 1980). The 1992 Environmental Research Associates poll found that America's children and parents lacked basic information on energy issues: few knew where electricity comes from now, only 7% of children and 18% of parents knew that coal is currently the primary energy source, and nearly half expected solar energy to be the primary energy source in 10 years (U.S. Council for Energy Awareness, 1992, 3). On the other hand, there is little evidence to support the view that more information or more knowledge would lead to more support for nuclear power. An overview of research in the early 1980s found two studies suggesting that more knowledge led to greater support, one study concluding the opposite, and several which found no relationship (Mitchell, 1982). It is likely that increased knowledge, rather than acting as an agent of change, serves primarily to confirm rather than to shape attitudes and that individuals selectively fit new information to existing belief structures.

These results are consistent, of course, with the preceding analysis of the multiple sources of public concern. Psychologists have also pointed out that more information to eradicate the "perception gap" may instead mobilize latent fears about nuclear power and actually increase concern. The various public information campaigns and referenda conducted in Sweden and other countries tend to confirm the limited ability of greater risk information to stimulate greater acceptance. 1992 industry-led public relations campaign to "educate" the Nevada publics about high-level radioactive waste disposal appears to have exacerbated perceptions of risk and public distrust (Kasperson, Golding and Tuler, 1992). The evidence, in short, continues to support the conclusion of Otway, Maurer and Thomas (1978, 117) that "to expect people's attitudes toward a new technology to be primarily determined by statistical estimates of physical safety is a highly simplified, and incorrect, model of human though processes—it implies such a degree of 'rationality' as to be itself rational."

PATHWAYS FOR INCREASED PUBLIC ACCEPTANCE

If public education holds little promise for solving the public acceptance problem, what does? The first response—a necessary one—is that the problem may not be solved. Not all technologies eventually survive the test of public acceptance (witness the case of asbestos!) and the jury is still out on nuclear power. And the eventual social judgment may well be different in different countries. Yet, with all the problems, indications still exist that the current public antipathy to nuclear power may not always be the situation in the future. Indeed, it is possible to imagine futures in which nuclear energy could regain its public mandate. The particular pathway to such a reversal of current social regard is, needless to say, highly uncertain and poorly illuminated. But a number of key considerations follow.

A Demonstrated Record Of Safety

The vivid portrayal in the mass media of the Chernobyl plumes moving across the expanses of Scandinavia, western and southern Europe, and the Soviet Union have doubtlessly added to the popular imagery of vast consequences of major nuclear accidents. Protective strategies, involving avoidance of milk consumption, washing of fresh vegetables, keeping children indoors, and distribution of iodine potassium, and the impacts on the Scandinavian reindeer and Lapps may well be etched upon the memories of publics throughout Europe and the Soviet Union. Then, too, the suspicion of some that nuclear power is surrounded by undue secrecy or has effects that cannot be controlled may be heightened by the confused national responses to the accident and by the problems in risk communication to the public. Most importantly, the evident public fright following the accident have surely add to extant public fears of this technology.

Earlier, the global response to Three Mile Island, the intense media coverage of the accident and related investigations (Kasperson and Kasperson, 1987), and the evident impact (in at least the United States) on public attitudes made it clear that the nuclear industry cannot survive many serious accidents. Conversely, it seems apparent that a demonstrated record of safety and the absence of major events would almost certainly contribute to reduced public anxiety about nuclear power. Chernobyl has made even clearer that accidents will occur, of course, within individual countries and on a global basis. Given the international flow of information and the publicity surrounding any major nuclear power event, accidents in one country reverberate strongly on public opinion in others. Even near misses are important because the performance of utilities and regulatory agencies during such crises send signals concerning the technological competence of safety managers as well as the candor with the public and the degree of institutional compromise (if any) in the commitment to candor and public protection. So an extended period of major accident-free operation of nuclear power and the successful handling of risk events when they do occur is a clear need for nuclear power. Another Chernobyl, meanwhile, could well be the death knell for public acceptability over the next period of time.

Containing Catastrophic Risk Potential

Related to a demonstrated record of safety is the particular issue of the catastrophic risks of nuclear power. Convincing evidence exists, as noted above, that the potential for catastrophic accidents underlies public anxieties over nuclear power technology. For many publics, there is little discrimination in the spectrum of reactor accident scenarios and a tendency to link any major accident with an assumption of worst-case consequences. Chernobyl has undoubtedly deepened this linkage.

During the current hiatus that exists in a number of societies in developing nuclear power programs, an opportunity exists to reconsider whether the particular reactor technologies adopted in the early history of the nuclear programs are the most appropriate ones for the next stage of nuclear power development. To the extent that technology or safety measures can be identified that effectively, and reliability, reduce catastrophic risk potential, and become more forgiving, important gains may be realized in increased public acceptance over the longer term. On the other hand, this has the all too familiar ring of nuclear safety claims of the 1960s and 1970s. Golay (1992) cautions, in regard to the hopes for improved safety, that "the uncertainties of these hopes, the difficulties of translating a concept into a successful design and the ability of even the most perfect hardware to be ruined through thoughtless use have been largely glossed over." And the accommodation of the passively and semi-passively safe concepts for increased safety and economic competitiveness is yet to be made. If these new concepts fail to end the debate among experts over reactor safety, then even improved safety designs may fail to translate into increased public acceptance.

Separating Military And Peaceful Uses

The historical linkage between destructive and beneficial uses of nuclear energy constitutes a formidable obstacle toward regaining a public mandate for nuclear power. It is quite apparent that, for many publics, destructive and peaceful images converge, whether in fears over major accidents, projections of the scale of destruction likely to occur, or possible contributions of nuclear power development to nuclear weapons proliferation. The scale of contamination of the Chernobyl accident has certainly reinforced, and perhaps intensified, this imagery. Greater clarification and separation between these two sides of nuclear energy use could possibly help to allay public fears over time. Possible actions could include sharp institutional separation between the management of nuclear power and nuclear weapons, more openness and public participation in the peaceful uses of nuclear energy, separate management programs for civilian and military radioactive wastes, bans or restrictions on the reprocessing of commercially—generated wastes, strengthening of the Nonproliferation Treaty and rectifications in current weaknesses in the existing international institutional nonproliferation arrangements, and restrictions on the development of the breeder reactor.

Rediscovering Nuclear Power Benefits

Where nuclear power has encountered major declines in public mandate, as in West Germany and the United States, perhaps no factor has been more important than the reduced sense that nuclear energy is a "beneficial" and "worthwhile" technology. Rediscovering the advantages of nuclear power appears crucial to a more favorable public response.

Such a changed assessment could occur in several ways. The gains registered by energy conservation and a sluggish global economy are likely, in time, to run their course, with new growth in energy use. Similarly, the declines in oil prices will not continue indefinitely and future energy "shocks" seem highly likely, whether because of international crises, declining oil supply, increasing consumption, or political surprises. Future energy crises could lead to greater appreciation of nuclear power's contribution to national energy security. This has certainly been a key to the relatively high public acceptance in France and (to a lesser extent) in Japan.

Several other pathways to greater appreciation of the benefits of nuclear power exist. Higher petroleum prices, more efficient and standardized reactor technology, and greater regulatory predictability could improve the comparative prices of nuclear versus other energy sources. Whether favorable nuclear electricity prices are achievable is a country-specific question, subject to temporal change, and a hotly debated topic. Similarly, the discovery of the environmental and public health prices of competing technologies, and particularly the contribution of carbon emissions to global warming, may lead to a greater appreciation of nuclear power as more environmentally benign than has been the recent prevailing public view.

A public assessment of increased benefits from nuclear power, particularly if combined with substantial progress on nuclear safety matters, could significantly affect overall acceptability judgments on nuclear power. Again, it is important to stress that actual progress in this area is crucial; information campaign claims unsupported by demonstrable progress are unlikely to have any significant impact.

Progress On Radioactive Waste Management

Radioactive waste management has been the most delayed and neglected nuclear fuel cycle problems across a number of countries and it has cost nuclear power dearly in its loss of public mandate. What first appeared as a minor issue to be dealt with routinely as nuclear power programs grew and matured has emerged as a volatile policy issue, one that stands at or near the top of public concerns over nuclear power in many countries. Indeed, the perception gap between experts and publics is probably nowhere greater than in this area (Flynn, Slovic, and Motts 1992). The conflicts over siting of radioactive waste facilities, as well as associated transport systems and the widely held view that there is "no solution" for radioactive waste problem pervasively erode the prospects for greater public acceptance. Indeed, the cautions turn about in Sweden for nuclear power is connected in no small part to the significant progress there on radioactive waste management.

On the other hand, the prospect exists that this is one fuel cycle problem on which substantial progress could occur over the next decade. A technical consensus exists that radioactive waste disposal is a tractable problem that may be satisfactorily addressed by several technology and disposal concepts. What is critical is that substantial progress occur in a timely manner and with a high degree of openness and social sensitivity. Demonstrable progress will not only reduce public concern over this particular risk area but build confidence in management institutions and in the technology. In this respect, the progress on radioactive waste management evident in Sweden provides optimism as to what can be done whereas the U.S. program, alas, continues as a model of how not to do it.

Fair And Equitable Institutions And Processes

Institutional failures have abounded in the management of nuclear energy. The nature of the technology has pressed toward a management system drawn from military origins, one characterized by secrecy and limitations upon public scrutiny and involvement. The commitment to public safety has not infrequently been compromised by advocacy of technology development or a reluctance to share bad news. Critics have had few opportunities to debate the merits of the technology or to find sympathetic hearing of their complaints. Complex technology and massive quantitative risk assessment have frustrated, rather than contributed to, increased public understanding. The "command and control" management system has proven singularly poorly adopted to the challenges facing nuclear power and the surrounding institutional and regulatory structure is a heavy anchor holding back progress in regaining the public mandate for nuclear power.

Risk acceptability, it must be appreciated, is as much a matter of the process that renders judgments as the particular levels of risks and benefits that result. Institutional mechanisms capable for addressing equity and fairness issues and providing for procedural justice are absolutely essential for increased levels of public confidence. The NRC/EPA/DOE regulatory system, as M. Granger Morgan (1993) has recently powerfully argued, is a "bureaucratic quagmire," with "technically mediocre" officials more often committed to self-preservation than to the future of the nuclear industry. It is an institutional system, be warns, in need of fundamental change:

> It is unlikely that the state of the current regulatory organizations can be fixed with a bit of institutional fine tuning. They carry too much old baggage—too many habitual ways of thinking, traditions, legal precedents, and other institutional encumbrances—ever to become the kind of smart, efficient, and responsive regulatory organizations that are needed (Morgan, 1993, 30).

BREAKING WITH THE PAST

Contemplating a new beginning for nuclear power must face squarely the legacy of the past and the host of problems that beset, and limit, future prospects for this technology. In the face of fading fortunes, the unwillingness or inability of those steering the course of nuclear power to respond and to adapt casts considerable doubt as to whether the navigators are up to the challenge. The challenge is nothing less, in our view, than breaking dramatically with the past—to use the prospect of a new technology to create fundamental and far-reaching changes in the whole nuclear constellation—institutions, management systems, nuclear culture, and people—that surround and imbue the technology. It is a daunting task but without such a dramatic break, it is doubtful in our view that a public acceptance turnaround and a new public mandate are likely.

This breaking with the past will be wrenching. It will involve a restructuring of the institutions that guide and regulate nuclear energy in the United States, with a new commitment to high technical expertise, a new commitment to high technical expertise, openness and candor, an uncompromised commitment to safety first, and an historical compromise with environmentalists. The current desultory and discredited approach to high-level radioactive waste management must be replaced with a new approach that is guided by the National Academy of Sciences's 1990 statement on "Rethinking Radioactive Waste Disposal" and that draws upon the Swedish successes with waste disposal, a new national resolve and program on low-level radioactive waste disposal that returns responsibility from the current state Balkinization to a centralized and economically sensible program, and a management approach to waste disposal with high adaptive capability. There must also be a recognition that the fragmented utility structure of the U.S. electrical industry is inherently limited in its capability to manage the next generation of passive or semi-passive reactors. And as Granger Morgan (1993) argues, political will at the highest national levels will be indispensable to steer the nation through these fundamental changes and to overcome the myriad of defenders of a self-serving and socially discredited management system.

RESPONSE TO R.E. KASPERSON

FEAR, IMAGE, AND VALUES

Thomas Hughes

My comments are directed to the authors' sections entitled "fear" and "value conflict and cultural setting." These sections draw attention to public attitudes usually slighted by engineers and managers who are advocates of nuclear power. They tend to see fear and values as irrational and do not take them into serious consideration in their engineering calculations. Culture, another topic explored by the authors, is a concept seldom explored in engineering studies. Parameters not defined as technical and economic they label soft. Soft is a pejorative term. As a historian, I have grown accustomed to having my engineer friends relegate history to the periphery of disciplines because they see it as "soft."

I remember sitting in an engineering course on nuclear power in which an unsocialized student asked the instructor about the risks associated with nuclear power. The instructor disdainfully dismissed the question as simply "politics" and unworthy of consideration in his class which was focusing on the technical and economic problems of nuclear power.

I have seen engineers and managers—to use Mike Golay's word—"blind-sided" by attitudes and events they categorize as soft. The nuclear power advocates have been and are being blind-sided by attitudes and events that Kasperson and Arvind subsume under the heading of fear and values. The link between nuclear energy and weapons; the images generated in movies like *The China Syndrome* and by novels such as Nevil Shute's *On the Beach* and Don De Lillo's *White Noise;* the anxieties caused by the brinkmanship of the Cuban missile crisis; the possibility of a rogue nation or terrorists exploding nuclear weapons; and the damage to genetic processes by radiation are images and events associated with fear. They contribute substantially to the negative responses of the public to nuclear power. Those engineers and managers who dismiss fear as irrational and who argue that the issues to be taken seriously are technical and economic are not responding adequately to the public's anxieties about uses of nuclear power.

A large segment of the public perceives nuclear power as contradicting some of their most highly cherished values, especially those associated with democratic processes leading to accountability and control. They also see nuclear power negatively because it runs counter to the high value they place on small scale, comprehensible, and environmentally benign technology. To many persons, small is still beautiful.

The advocates of nuclear power are imprudent to dismiss fear and values as soft and irrational Fearfully associating the image of a nuclear mushroom with atomic power as well as atomic bombs is not irrational since Chernobyl; linking catastrophe with melt down is not irrational since Three Mile Island. Fears that rogue nations and terrorists might explode nuclear devices have more credence since the theft and disappearance of nuclear materials in the former Soviet Union and eastern Europe. The probability of melt downs and terrorist bombings may be low, but there is no direct correlation between fear and probability, as those who walk inner city streets at night know.

To inform inner-city pedestrians statistically, to tell them that on a macro level they are in less danger to life and limb than they would be on the nation's highway does not cause fear to dissipate. Fear of nuclear accidents and of radiation from waste is more like fear of an assailant in a dark alley than like the trace of anxiety one feels driving on crowded highways—statistics notwithstanding. Psychologists have more insights into the varieties of fear than statisticians and logicians.

I have encountered a few advocates of nuclear power who respond effectively to hard fear. Several years ago I took a graduate seminar in the history of technology from the University of Pennsylvania to visit Three Mile Island. This group of post-1960s scholars was not favorably disposed to nuclear power. Within the first twenty minutes of the tour, the Three Mile Island management had the technician in charge of the control room at the time of the accident tell of the concatenation of events resulting in a complex, unpredictable set of interactions within a tightly-coupled technical system prone to normal accidents. In a follow-up discussion the management forthrightly stated that this accident could happen again. We were told that this was the message to the employees at the plant as well. The students were won over by the willingness of management to take fear seriously. We were told that the employees are more sensitive and responsive to problems and latent dangers because they have been told that a serious accident could recur.

Not only fear, but a counter-culture value system took shape in the late 1960s during the Vietnam war and that is still influential today work against nuclear energy. Kasperson and Arvind do not cast their net broadly enough in linking the anti-nuclear power public simply with specific issues, such as the environment. Those espousing counterculture values in the past and today have encompassing, interactive concerns. They accuse large profit-making corporations of being indifferent to environmental damage, unconcerned about alienated labor, and callous about product safety and reliability. They attack government bureaucracies for being impervious to public scrutiny and control as they pursue self-aggrandizing goals. Corporations and government are seen to be thoughtlessly and exploitatively committed to economic growth without regard for its negative social impacts. Government and business during the Vietnam war were perceived as hierarchical and violent. Technology was and is at the heart of the despised system and nuclear energy the essence of all that was and is negative about technology. Kasperson and Arvind rightly recommend using "new technology to create fundamental and far-reaching changes in the whole constellation—institutions, management systems, nuclear culture, and people—that surround and imbue technology." (p.25)

On the other hand, there are numerous example in the past of technology having links with positive images and values. In nineteenth-century America disastrous accidents, financial skullduggery, and cruel labor practices plagued American railroads, but the new nation valued the new transportation system as means to fulfill the country's manifest destiny of nation building and western expansion. Big manufacturers and utilities presided over the electrification of America, but the people associated electricity with the heroic, self-made Thomas Edison, with the festive lighting of the Chicago World's Fair in 1893, and later with the convenience of home lighting and appliances. Henry Ford built a manufacturing empire that relentlessly worked laborers on the mind-numbing and body-wearying assembly line, but Americans had an image of Ford as providing mobility and pride of material possession to the common people in a great democratic setting. The Tennessee Valley Authority, a massive technological system, inspired a host of Americans to view government projects as the means to transform a poverty-stricken region into a model of economic development. Abroad, large numbers of the French associate nuclear power with national prestige and many Japanese see nuclear power as relieving their energy-poor country of dependence on imported energy and on the policies of other nations. In short, other technological systems have ridden the crests of waves of popular aspiration including manifest destiny, democracy, and socially benign economic development.

So I return to my reading of Kasperson's and Arvind's policy recommendation. Proponents of nuclear power in the United States need to transform the technology dramatically so that the characteristics of nuclear power will harmonize with today's popular value systems. Today, the technical characteristics, the managerial forms, and the social consequences of nuclear technology do not fulfill the transcendent values of a post-1960s influential generation of Americans, a generation highly valuing such goals as institutional accountability, renewable technology, small scale technology, environmental quality, and the equitable distribution of economic welfare.

Technology has been and always will be socially constructed and it will embody values in addition to those associated with economic rationality and technical efficiency. Present-day nuclear power technology and management express the values of the 1950s—large scale, mass production, technical complexity, and hierarchical, bureaucratic management. The technical hardware can be compared to the gasoline consuming and tail fin sprouting automobiles of the 1950s. The public awaits a nuclear technology that is representative of a culture valuing the environmentally benign and the small scale, the flexible, accessible, comprehensible, and accountable as well as the safe and economical. Nuclear systems can be socially constructed through design to fulfill these aspirations.

CAN NUCLEAR POWER GAIN PUBLIC ACCEPTANCE?

DISCUSSION

U.S. Energy Researcher:

It is quite clear and has been for a decade that the public does not accept nuclear power. This is our condition. It seems in order to win public acceptance that the choice is twofold: it is to change the public, or to change the technology. The surprising thing has been that the nuclear power industry has decided it is far easier to change the public than to change the technology. This is not the usual response for a technologist. You always have available the technological solution to any problem, but wonder why this should be a peculiar aspect of nuclear energy.

I was interested to see that several people did get to the essence of the matter this morning. We were told the parable of the paper reactor, where the argument, of course, is that no paper reactor is going to catch up with any real reactor. This is a very strange piece of technological defeatism, because it implies that things can be different only in degree and not in kind from the technology which we have now. I say that differences in degree in reactor improvements are not going to be enough to gain public acceptance. Yet the nuclear energy industry insists that this is the only possible solution.

This is the equivalent of RCA back in the late 1950s, early 1960s, pointing out that transistors are relatively finicky devices and vacuum tubes are more reliable. It is also equivalent to Curtis Wright [Aircraft] claiming that reciprocating piston engines are always going to be superior to the jet engines just emerging from R&D laboratories. I claim that, if the nuclear power advocates would like nuclear power to be used, then those advocates who are for nuclear power must find a technology that the public will accept. Failing that, the public will not accept nuclear power and it will go out of business.

U.S. Nuclear Power Industry Professional:

I agree with pretty much of what the previous speakers all say. I believe that in order to gain public acceptance, the next generation of plants must have a superb operational base, a superb technological base, and a superb managerial and regulatory base. I think, as we look forward from where we are today, that we need to make a giant step in the way we run our industry, and how we build it.

I would like to note only two plant characteristics that I believe are important to strive toward in the future. We are working towards these characteristics to some degree, but we need the support and the direction of people in this room to go in the desired direction. The first is standardization. It is a word that has been discussed for years. I submit that standardization is one of the most important things that we can do, that is to insist that all nuclear plants being built are built as part of standardized family of plants. So, we can have standardization of families of power plants and also standardization in terms of the technology which we can use.

We will have available in the near future one standard design which is that of the so-called evolutionary plant, and also of the passively safe plant. The former is large, the latter is small. By PRA evaluations they are both safer than current plants, and they are well enough thought-out that they incorporate the lessons which we have learned. They give us the chance to do the things that we know are right.

The evolutionary plants are today a cross between paper and reality. They are an advance. They are not just a paper, but they are not only what they have to be.

Building standardized power plant families can do two things:

- They can provide safer plants because the lessons of experience are better understood; and
- They can decrease the plant costs because they are easier to regulate [by safety authorities].

I would like to define standardization in terms of three tests concerning whether or not we have a standardized family of plants. The first is for each staff position of any one of the standardized plants to be able to be filled by a staff member holding a similar position at another plant in that family, except perhaps for plants on ocean water, or river cooling system. The second is that each plant is an independent business unit using the same accounting procedures, manpower controls, etc. The third is very important. It is that each plant is supported by a central owners' control support facility. My intention is that this facility does all of the work that does not have to be done at the plant site. Those are the three criteria. We can be successful using a worldwide family of similar plants.

The second characteristic concerns an information management system (IMS). An IMS can only flourish if we have standardized plants. Such a system can reduce costs, it can improve safety, and it can improve regulation. Now, what we do I mean by an IMS? The best example that I know of is a system made by Black and Veatch called PowrTrak. What we need in order to develop a family of plants is an IMS which is well thought out—to a degree so that we can substitute for the irregularities of engineering, the irregularities of procedures—and the other vagaries that occur at many different plants. We need to do many things, and standardize them with a great level of review and origination.

Through use such a system we can obtain a predictable power plant construction time. We can also minimize the plant staff size, and I believe that we can make our plants in the future to be competitive with any other technological form of electricity generation. I also believe that such plants will be safer, and they will be perceived as such. With use of the IMS and standardized family of plants, the associated nuclear power plant management structure will become transparent. I think that this will be a big advantage to anyone who is looking for credibility in the future for our nuclear power plants.

Academic Socio-Technological Scholar:

I get the impression that our speakers are saying that nuclear plants are now donkeys and unacceptable, and that the problem solution is to make them into real horses so that they will then be acceptable. The true question is that of "can we have them made safe enough to disarm the critics of nuclear energy as the source of all evil?" I agree that there is a social and cultural change which has been taking place concerning the image of nuclear power. It started in the movies in 1950, with ants becoming monsters as a result of a nuclear explosion. It did not begin with the *China Syndrome* movie. There was always a high level of fear about nuclear energy, although it may not have been measured well.

For nuclear energy to succeed it has had to have the support of the important elites in any society. Recall that in the 1960s nuclear energy was being supported by the [radical] Students for a Democratic Society (SDS). Then in the later 1960s it became the epitome of capitalism, reaction, and Vietnamism, and there was a corresponding loss for nuclear energy of the support of top, or skeptical, elite. This occurred even though the scientific community as a whole, in the United States, Germany, Sweden, has always regarded nuclear power well.

We can see how nuclear energy became associated with these things because, as one of our speakers has said, nuclear energy became associated with the self-image of capitalism. Barry Commoner would run around in those days saying that it was capitalism which made the nuclear power plants unsafe. This was before we knew what was going on in the Soviet Union and China. You do not hear that very much any more. However, attacking nuclear energy became a way of attacking capitalism during the Carter administration and for many people of that generation.

I am quite sure that any measures taken to make nuclear plants safer are not going to persuade people that they can be safe if the people do not want to be persuaded. However, they will not persuade people that any waste disposal system will be proven successful 10,000 years from now. When any waste disposal proposal is tried it will be impossible to demonstrate that it will work. It seems to me that before you can try any alternative, some people, in any event, will always say that this will fail.

Also, I am not persuaded that more public participation is going to make nuclear energy successful. Of course, you can compare the United States to France—a country in which nuclear energy, in fact, has been successful. At least it was about ten years ago; I have not seen recent data. The French were initially as hostile to nuclear energy as were the Americans. The difference between France and ourselves was that they did not have the same openness as ourselves in the process by which decisions were made at a technical level. The population was told take the nuclear power plants, and then after the nuclear plants began to work successfully the attitude began perhaps to change positively.

I am not sure that the democratization of the decision-making process of this country, or that better education will improve the situation of nuclear energy because this country has always had democratization. Also, at least one country has found that just the opposite way succeeds in persuading, or at least gaining public acceptance of nuclear energy.

The real issue seems to be that of whether we are too late. I suspect we are, if we must get nuclear energy acceptance by the relevant elites of the society. By relevant elite I mean those involved in the spread of ideas and the change of culture. It is necessary for them to accept nuclear energy as a relatively benign and as a relatively safe source of energy. Unless they do, acceptance of nuclear power is not going to go anywhere. I am not persuaded that their acceptance of the technology will increase result of technological decisions or technological improvements, unless those technological improvements are miraculous and provide fundamental breakthroughs. In such a case I suspect that the elites would no longer be concerned with nuclear energy.

U.S. Nuclear Power Industry Professional:

At the risk of being in a minority of one, I wish to say that I do not believe that the American public is opposed to nuclear power, and I have some facts to back this up. In doing this I wish to disagree with Table 1 shown by Dr. Kasperson. The organization that I work for, the U.S. Council of Energy Awareness, has for ten years tracked the American public attitude about nuclear power. We poll the public every February, and we poll opinion leaders every March. Opinion leaders to us are vibrant people; they are federal legislators, federal officials, state legislators, state officials, business executives, financial executives, public interest groups, national media, local media and academics.

We find that when asked the question—do you think that nuclear power should play an important role in the future of the USA—69% of the public at large believes yes; 72% of opinion leaders believe yes. Another poll was done in December 1992 and January 1993 of 302 representatives of U.S. House and Senate staff. Of the congressional staffers, 83% believe that nuclear energy should be important to the future.

The anomaly of this thing concerns a further question: "Do you believe that a majority of the American public feels that nuclear power should be important?" Of the public, only 33% of them thought the American public majority would believe that. With the opinion leaders, the affirmative response was down to 27%; with Congressional staff the result was 54%.

So, there is a feeling among the population generally that nuclear power should be important in the future. However, when you ask: "Do you want to build a nuclear power plant in your neighborhood?" the response is that 22% say yes. This last point agrees with Dr. Kasperson's table. Also, several respondents say that they would like to preserve the nuclear option.

Then we went further, asking: "Should we build a coal-fired plant, ... a hydroplant, ... a fossil-fuel plant?" The positive results were almost identical to those for a nuclear plant, at about some 20%. If you ask the public: "Do you think your utility should build a power plant, or needs to build a power plant, during the next ten years?" The affirmative answer is again about 20%.

What you are seeing is that the American public does not see a need to build any power plants. This is because the majority of them do not realize how electricity is produced; one can simply move a switch and turn on a light. This is not new.

At the turn of the century if you went to Manhattan hotel you will have found an electric light, because this is the first place that electric lights were widely used. On the wall you would have found a plaque saying, "Contrary to popular opinion, electric lights are not harmful to your health." I was lucky enough to have one of those signs in my office.

Also, if you read Dixie Lee Ray's book, *Trashing the Planet,* you will find reference to a congressional register article about a new technology that has the power to relieve the

American public of many of its problems, but which also is so dangerous that it should be highly regulated. This entry appeared before the turn of the century. It was discussing the internal combustion engine in the automobile.

Thus, people distrust technology. I agree with that. People have developed mistrust during the past. It is up to us to try to get them over that attitude to the point where they can use this new technology that has a great potential for improving the life around the world, but which also needs to be regulated.

Public Policy Analyst:

I join Roger Kasperson in having degrees in geography. I have taken rather a different course, however, being one of those who apparently is rather being denigrated by some of those whom we are hearing today. My concern is for the totality of the environmental and public health aspects, as well as safety aspects associated with the nuclear energy industry. There are three areas which are, I think, at the core of the dismay and the public's disaffection with the nuclear technology.

The first of these is the issue of radiation impact. I think that it would behoove the engineers here to hear a paragraph or two of the contemporary medical view of radiation effects based upon recent biological research. This goes to the heart of what is termed a fear, but which is actually a legitimate biological concern.. A new volume of a medical guide to physicians for the diagnosis and management of radiation effects upon the patients says:

> "Ionized radiation targets only a part of any one of the billions of atoms in a single cell. Its energy is dispersed unevenly among many atoms of any of the approximately 75 trillion cells in the human body. No two people or even comparable DNA segments of any two cells can receive the same dose of ionizing radiation. Much more molecular damage is done by ionizing radiation before symptoms can be recognized. Few radiation recipients will have early identifiable symptoms, though some may exhibit a symptomatology, including teeth, joint and muscle pain, and gastro-intestinal discomfort, but no two will have the same clinical picture."

Now this provides the physician with information which is not common even in the medical literature. It says that indeed there are biological impacts of ionized radiation. In understanding this, we have been looking at effects after the fact, and only at some of the consequences of those exposures; after long latency periods, which are clinically observable. Some of the work coming out only now from radiation biologists and physicians in the former Soviet Union challenges classical assumptions concerning the effects of ionized radiation, particularly at chronic low doses.

I hope that every engineer in the room is acquainted with this new literature, but perhaps not. We all have difficulty with cross disciplinary specializations, I am afraid, in our information-rich age.

So the foundation of what is correctly perceived to be a public reluctance or total unwillingness to accept nuclear facilities after 50 years of developing the technology is not based perhaps upon a detailed understanding. Rather, it rests upon a fundamental grasp by the public that ionizing radiation is indeed a mechanism of genetic change and biological injury. That is point one.

Point two: At the mention of the term "values," I perked up my ears. I have spent many years in the realms of alternative energy, conservation and efficiency. Perhaps we ought to call it CEA: Conservation, Efficiency and Alternatives. We need to consider them if we are ever as a society to develop any kind of sustainability in our economy and energy supply. Our way of life needs to go to focus upon value systems which govern what we use and how we use it, considering how wasteful as a society we are willing to be. I am very glad that such questions are beginning to be addressed by those associated with nuclear power and its promotion.

Point three: I find myself concerned more and more with our culture. We are brought up with an almost universal belief in technology as a religion. We are very close to having a religious faith. It contains a belief that through advances in technologies we can also solve all the problems created by those technologies. For me as a geographer, we look at the intricate underpinnings of the physical earth, with technological systems and the vagaries and human frailties of political and economic systems, combined with very real resource and economic limitations; they all begin to impinge upon our culture as a whole. We have to take those considerations together into our evaluation of the likelihood of acceptance and the capability of nuclear power in comparison with other technologies to succeed in the kind of cost benefit analysis discussed here which transcends the customary kind required under the law. This analysis becomes a matter of societal consideration and debate. I would like very much to see those who within the nuclear industry address these questions in earnestness.

International Nuclear Power Industry Professional:

I want just to give you information about the situation in Italy regarding public acceptance of nuclear power plants. Probably most of you know that we are in a unique situation in the world. We are the only country which has shut down all of the operating plants, and stopped the construction of two units which were 70% completed. At the same time we are also in a unique situation because we continue to obtain about 15% to 20% of our electricity from nuclear energy, coming from France.

This decision was imposed upon us, the utility owned by the government, as the result of a referendum held one year after the Chernobyl accident. So, no blame has been laid upon the operation of our plants. We have had no accidents. We have had a very good record of safety, and no specific problems. But the effect of the Chernobyl accident upon the attitudes of the people was so great that many people apparently became opposed to any nuclear power plant. The fact that this was mainly due to the fear of a large catastrophic accident has been shown by a recent poll, which reflects the NIMBY (not in my backyard) syndrome. When people were asked whether a new plant should be built in Italy, only 37% were positive. But, to the question of whether they think nuclear energy has been a good choice for France, the positive percentage raised to 52%. Then, people were asked whether they think that nuclear energy is good for Japan and the positive number is 57%. So, I think that this shows that the proliferation issue is not a central objection to nuclear power, at least not in Italy.

Mostly the opposition is due to the fear of a catastrophic accident. Therefore, since the government asked us in the industry to study and develop next generation plants promising improvements in safety, we started to work together with organizations in England and the U.S. Also, within the European environment for plants the government asked that we compensate for severe accidents in the design.

I think also that it is important to recognize that 50 years after the first critical pile built by Fermi that nuclear energy should be considered to be a mature technology by now. It should be considered to be, at least, as mature as most of the other desirable industries. Therefore also, the degree of safety scrutiny should also be similar to those other industries. Otherwise people will feel that nuclear energy is more dangerous than other industries.

So, the civilian safety treatments of nuclear energy should be harmonized both at the level of each country and also internationally. This is really important. We think that convergence in licensing procedures, design criteria and action limits are very important. They should be harmonized internationally. This is true, particularly for emergency planning and evacuation planning. It is because we have such difficult rules and treatments in some cases, we think, without justification, that convergence is needed.

Public Policy Analyst:

My question is to Dr. Kasperson about what you think would be the public response to a diversion of weapons-usable material out of Russia—either from the weapons program, or the civilian program. Earlier, Dr. Budnitz mentioned a high probability of a core disruptive accident in the former Soviet Union. I think it would be a close bet, whether such an accident would occur before or after the next division of nuclear materials. I am uncertain about what the repercussions are likely to be should that occur.

My comment is that, since this is an International Conference, it is notable that most of the discussions, particularly in this session, seem to focus on the United States situation. One of the earlier comments was that there are two alternatives for gaining acceptance of nuclear power—

either changing the technology or changing public opinion. Going back to an earlier comment that nothing has changed over 20 years, I think that we have learned that neither the technology nor public opinion is going to change.

Rather, I think that there is another alternative that is not being discussed here. Rather than change the technology or the public's attitude, the other alternative—and it is the alternative which the nuclear industry has pursued—is to change your market to countries where the public attitude is not important in national decision-making. This market includes China, South Korea, Japan, and maybe Taiwan. The more likely future is that where the nuclear power technology will limp along with money being made in the fuel business and from safety improvements, with new sales coming from countries where public attitudes are not important.

It might be worth spending some time on what that future is going to look like rather than continuing this debate over public acceptance which we have been having for 20 years, where I think we all know the answer. None of the parties is going to change technology. Anybody that knows nuclear engineering knows that you cannot change the technology very much, and some of us do not think you can change public attitudes very much either.

Prof. Roger Kasperson (Clark University):

My response to the question is that whether weapons material diversion were a major event would depend very much on the circumstances, the consequences and the way it is handled in the press. Perhaps the most important factor would concern whether a diversion would rekindle a new period of debate about this particular problem. This aspect of nuclear fuel cycle problems then could only have a significant impact on exacerbating public concern over nuclear energy.

One of the things we discovered about nuclear power, I think, is that the metaphor has been wrong. About 15 years ago my colleagues and I wrote an article in *Science* called "Distrust of Nuclear Power." We said that what you are really seeing with nuclear power is a hydra kind of phenomenon, where the nuclear industry succeeds in putting one particular issue to bed and two others spring up. I think that there is a continuing problem in the nuclear fuel cycle. The debate continually shifts from area to area, all of which exacerbates the fundamental problem—the public response to the technology. So, some event can encourage the movement of debate to one of these new issues and then it comes to dominate a period of debate for the next four/five years before it shifts to something else. I think that this has a cumulative negative impact on attitudes.

Prof. Thomas Hughes (University of Pennsylvania):

I will comment since I am offered the opportunity. I would not be so pessimistic that a dramatic change will not occur in technology. I can think of a number of such changes in recent history—for example, the change in the technical characteristic of the American automobile partly as a result of the 1973 energy crisis. Another more dramatic example is the change of the British electric industry in the 1920s when they had a small-scale electric utility system. Utilities initially supported approval of a number of laws so that it would remain small-scale and local. But then Britain became concerned after World War 1 with its position in world politics, in terms of economics as well as foreign affairs. This concern recognized a decline in the United Kingdom's competitiveness among nations. We must adjust technology in order to reinforce the economic strength of the nation. So Britain introduced her first national electrical grid. It was a dramatic change from the small-scale technology which that country had been dependent upon. You can add a number of examples where value shifts have brought almost dramatic changes in technical characteristics.

U.S. Energy Researcher:

I would like to comment on some prior remarks concerning Japan. The majority of the Japanese public still supports nuclear power, if you take a poll. But this is not because the Japanese public do not fear nuclear technology. The same poll indicates that 70% of the people are afraid of nuclear power. So, the existence of public fear does not necessarily mean that you discard the technology. The big difference between the Japanese and American publics, I think, is the sense of a need for energy. The American public probably thinks that the country will survive without nuclear power. But in Japan, most people still think that we cannot survive without nuclear power. That is the biggest difference between the two countries.

' The previous comment concerning the role of public acceptance in Japan, I think, is incorrect. In Japan, public acceptance is also very important. For example, the role of nuclear public acceptance in Japan is also different in a very important way concerning the siting issue. For instance, in Japan siting is becoming very difficult also. In the 1960s and 1970s, it only took about another seven years to build a nuclear power plant from the time of the proposal to the completion of the plant. Now, on the average it may take up to 20 years. So, siting is becoming very difficult.

Also, with the Mihama nuclear power plant incident, public was strongly opposed to the way that Kansai Electric Co. provided information. One of the issues was that Kansai Electric Co. said that there was no radiation leak from the power plant. But later they found out that there was a small leak after all, and the public became opposed because maybe the utility had told a lie. So now the utility has installed ultra sensitive radiation monitoring so that they can detect even a small leak releasing the level of activity. This shows a sensitivity to the interest of the public. Those are the same attitudes that most people outside of Japan have, also.

Public Policy Analyst:

I think the fundamental underpinning problem for nuclear power is that the utilities and the government have lied to the American public, that trust has been broken, and that enormous amounts of effort, time and money have gone into public relation campaigns. I am hearing today in this meeting words like small, standard, the family of plants; and I think instead that as members of the family of man, we simply have to start telling the truth to one another. Families do not lie to one another and we need to restore personal integrity. We need institutional integrity, and most of all in this room we need scientific and research integrity. We need money to be put into building public trust in order to assure that we can have scientific credibility. The credibility of the nuclear industry has been their public relations campaigns of misinformation to the public. We are not fools.

Academic Socio-Technological Scholar:

A consensual, collaborative approach to gaining acceptance works better or works best. Acceptance is a process as well as an outcome, depending upon the circumstances. A consensual process works from the bottom up as opposed to one trying to get acceptance from the top down. Throughout a process such as this you are most likely to encounter some successes and failures along the way. You are trying to build trust. This is something that you are just going to have to accept and acknowledge. You will be constantly tested and must be reaffirmed.

As has been mentioned previously, the industry does have a credibility problem. It is probably the only industry that I have studied and worked in that has not felt a need to defend its product. Indeed, usually a company must fight to retain its market share. However, the nuclear industry does not necessarily do that unless faced with competition.

There has also been a certain amount of talk today about the public, reflecting some sort of implicit belief that the public is a homogeneous entity. It is not. It is really composed of many different publics, many different groups that have different issues and concerns. Reaching the different publics will require different messages, different pieces of information. There has also been a tremendous concentration upon safety, which will always be present. However, I think that we are in a position of trying to defend a need for nuclear power in light of alternatives; and particularly renewable resource alternatives. We are trying to frame the nuclear alternative in ways that the public will relate to, not simply in terms of quality land used or the cost of energy delivered. Rather, we must consult with the public to develop outcome measures that are responsive enough to the public's particular concerns.

It is my belief that the success of the nuclear power industry in the future may hinge on giving up some power. By that I mean that you cannot execute this process in an institution that has been accused of abusing power. We may be able to disarm some opposition by maybe giving up some of our power and reexamining our traditional beliefs of what we believe power to be.

International Energy Researcher:

I agree strongly that we need to continue to give correct information to the public, but this information has to be easier to understand also by a layman, so we need information able to lead to a correct risk perception by the public. I think that we may consider only a few examples: surely plant simplification is very important, not only for improving the reliability, but for improving and simplifying the understanding of the function of plants by the layman, by the public.

Regarding new technologies, they have to be different at least in concept, but maybe not so different as not to allow us to use our experience. This experience was acquired in the operation of many plants, giving us 5000 plant-years of experience until now.

So, simplification is very important, intrinsic stability and having a negative reactivity coefficient are also important, and hopefully will not be seen to be so insignificant when evaluated by the public. No necessity of operator actions, at least for a reasonably long time during an accident is a very important feature. And last but not least, in my opinion; one of the first, actually is, a strong and very reliable diagnostic system that is very easy to be understood by everyone.

Prof. Michael Golay (MIT):

For those whom I have been unable to recognize to speak, I want to ask you to hold on to your thoughts. If this Conference is like the last one, the theme of public acceptance and the factors that affect it will continue to arise as the meeting goes on. What I want to do now is turn back for our two speakers and ask them to take the different strands of thought which have flowed out during this discussion and to put them into a coherent picture, and then to add their own ideas; a daunting challenge!

Prof. Kasperson:

I want to emphasize a series of comments that have been made following my presentation, which when viewed in combination present several important issues. We see an opportunity that at a time when there may be major technological change that will occur, with necessarily some aspects of social change accompanying them, to create new management structures and new organizations to resolve the problems of the nuclear safety and economic performance, etc. Perhaps in such change there is an opportunity to confront a larger set of issues that arise with the technology. This is a point which I wish to emphasize.

From the public acceptance perspective, what will really be required is that the technological change be seen as an opportunity to create a broader set of cultural and institutional changes which will absolutely be required if there is to be a new generation of nuclear power, and if there is to be a restoration of the public mandate. I would like to point out very briefly that if one views matters in historical context the nuclear power industry inherited a particular kind of institutional and management system. It was one really borrowed from the military. Much of it came from the navy. It was a kind of a management institutional system that gave a preeminent role to technical expertise, which closed decision-making, in secrecy, at some level; and relied upon a basic command and control kind of operation.

It is really instructive to view these matters internationally. We have had several international comments that this system is undergoing revision in many countries. This is most apparent concerning radioactive waste. When we examine nations in advanced industrial societies, we find that the traditional system is not succeeding in the task of managing the technology or in realizing its potential. We also note that a great deal of constitutional innovation is going on in the radioactive waste area.

There are basically new ways of relating to the public being tired in almost every country in the advance industrial societies. The kind of institutional system and approach that was begun with us was scrapped, and mid-course corrections are being made. Experiments are going on about how to fashion this kind of culture, and its institutional systems for a new way of relating to the public. My encouragement would be to see this as a period of opportunity, where symbolically you can really use the technology to motivate a series of other changes and to try to explain that opportunity. At its greatest, there may be some opportunities to improve both the nuclear technology and our energy systems in general.

Prof. Hughes:

I heard in the discussion a commendable willingness on part of the persons involved to see technology as an expression of values that are more varied and complex then would be understood by viewing things merely within the technical and economic spheres. From the conversation that I have heard around the table, many people here are willing to recognize that technology speaks to other concerns in a simple way, which make technology much more interesting.

When I think in terms of images from the past, Henry Ford's automobile provides a case in point. The effect of the automobile has been so great in this country, because it is seen as being powerful and it accorded with democratic values. Europeans who developed automobiles made them for the bourgeoisie, while we were developing a populist automobile in America. Also, as I said concerning the railroad, we had the wonderful image of railroads pushing west, being the instrument allowing the American people to bring an overall great civilization to the continent.

So, I think that it is very encouraging that those responsible for nuclear energy are willing to take into consideration the more difficult problems which transcend the economic and rational. Having come from an engineering school, I have enjoyed dealing with economics. It is clear, clean and elegant. Those messy complexities beyond the economic are also very challenging, and I hear the group here also discussing those.

RAPPORTEUR SUMMARY #1

Kent F. Hansen
Massachusetts Institute of Technology

RAPPORTEUR SUMMARY #1

Kent F. Hansen

My understanding is that a rapporteur is supposed to summarize the important ideas that develop and emerge in the discussion, and also to highlight the differences in the perspectives of those ideas. I have an advantage and a disadvantage in doing this: The advantage is that I was not here for most of the morning—I was teaching a class; my disadvantage is that I was not here for most of the morning because I was busy teaching a class. Therefore, in my opinion, I can say anything I want—and I intend to.

First, I was struck by one observation: The title of this Conference is "... on the Next Generation of Nuclear Power Technology." To this point I have not heard one word on the classic argument concerning whether the next technology should be an advanced LWR, or should it be an LMR? None of that has been broached, which makes me think that the important issue of the Conference does not concern the particular technology to be used in the next generation, but under what conditions will there be a next generation. That seems to have been the focus today, and that is probably appropriate.

In his paper, Prof. Golay has summarized the current state of the nuclear industry which he calls static. I would agree—static not only in terms of operating plants, but static in terms of the development of new technology. He suggests that there are conditions under which there might be future nuclear power growth, including those arising either from benefits perceived from nuclear power or from concerns about energy alternatives that may not look attractive. He uses the phrase "critical elite," which was used again by Prof. Kasperson a few moments ago. I like that phrase. Years ago when I was a graduate student taking my first course in reactor physics, I can across a quote from Shakespeare's Othello "Iago speaks the lie for I am nothing if not critical," which for nuclear engineers is a moral script. I took it to one of our professors and showed it to him, and he looked at me and said "If you have time to read Shakespeare, I am not giving you enough homework." But the term "critical elite" sticks in my mind. He also talked about the public acceptance impasse of nuclear power, and about life without it.

I am struck that there was a positive observation concerning the role of nuclear power, which indicated that developing countries will need energy in the future, and nuclear is one of the very attractive offerings for them. But there are also negative observations: one of which concerns safety and the questionable ability of developing countries to operate a safe nuclear economy, and also concerning nuclear safety in the former Soviet Union.

He also notes that there is a very strong linkage between the commercial nuclear industry and nuclear weapons proliferation. Regardless of how hard one might try to have a conversation focused solely upon the state of nuclear power today, that linkage occurred over and over again as it might occur again tomorrow. This is clearly one of the dominant themes about the nature of the nuclear enterprise today.

There were also comments about nuclear waste remaining a problem, and it certainly is a problem. Anybody in the nuclear power industry is aware of that. I suspect everybody else is aware of it also.

I heard Dr. Kadak's comments about how long the current plants will operate, and he did not surprise me when he said it depends on economics and politics. I think that is true of almost all of our enterprises. He was concerned about the economics and safety regulation. Those are certainly issues which have been in front of the industry in the past. It is interesting that they may also stop operating plants today for the same reason, even if they are no longer of concern for new plants. It is a concern for operating plants. Mason Willrich made it clear that the issues surrounding nuclear power have not really changed very much, but the framework has. In the past you talked about some of the intrinsic factors such as the industry structure, management quality, risk-averse public attitudes and breaking the vows of the social contract that existed between the regulated utilities and the public. Some of the extrinsic factors you would mention include economics and deregulation in general, and competition, which is now available or facing utilities.

I will make one observation at this point, or perhaps a question. It concerns whatever technology is cheapest today. My understanding is that currently this is the combined-cycle cogeneration technology, but I doubt it is going to be cheapest tomorrow. My guess is that the time constant for changes in the relative economics of any nuclear electricity generator is much shorter than the life of the plant. As a society, I do not know how you deal with that. Are we always going to make decisions based upon the current conditions; or should we make the future generation pay what may turn out to be our inappropriate investments. Today, absent the capability for seeing the future, I do not know how we can make an investment on any other basis, but in any event it strikes me as a serious problem for planners in the future.

The issue of gaining the trust and confidence of the public versus that of gaining the trust and confidence of the utility regulators also struck me as an interesting issue. I am not sure where we will end up on that one. I think that everybody agrees that the level of trust between the utility and its regulator, and between the public and the utility, are both at all time lows, and I am not certain whenever they will return to former levels. Prof. Kasperson had a number of interesting observations: the metaphors with which the industry views the nuclear power plants and the metaphors with which the public views the same plants are very different. I thought he highlighted those very well. Most of us in the industry see a nuclear power plant as a factory that produces energy. I think that the public has a number of metaphors which are profoundly different, that relate to population poisons, nuclear weapons, etc. There is a mismatch in metaphors that probably has to be addressed at some time. I thought that his graphic displays regarding the long term decline of the industry were very interesting, as were his observations that the perception of the benefit has declined and the perception of risk has climbed.

I think that those were crucial observations. I think that his comment that public confidence in institutional leadership is declining is very relevant. Personally, I was relieved to see that at the bottom of the rank list of esteemed occupations which he gave was the U.S. Congress. I am glad to know the public has caught up with my understanding. Finally, I have appreciated his outline of pathways for nuclear power to gain increased public acceptance. I thought that these were genuinely useful observations.

Prof. Hughes spoke about the conflict between the soft issues, and technology and economics. I agree with him wholeheartedly. I believe that there is a critical elite, that they matter, and that we need to work with them. The observation about technology being a hero in the past was also particularly relevant. I suspect, for a large number of us in this room who are engineers, technology was a positive aspect of the life-style in our families, and that it is more than just a factor in dealing with the public. To a number of us, technology advancement is a career path which opened doors.

There was one other comment that I was struck with which I will mention before I end. Mr. McDonald made some comments about nuclear power plants standardization. I disagree with that description, and the reason is that for years we have done studies on performance of nuclear plants around the world, and the world's best performing plants are in Finland and Switzerland. Year after year they have rated high on performance in terms of high capacity factors, force shutdowns, and the like. Neither one of those countries has an indigenous nuclear manufacturing industry. They import the technology from elsewhere. The Finns have imported Russian reactors and have then added to them a lot of western technology, including control systems and safety systems. They have also imported Swedish plants; they have PWRs and BWRs, both of high performance. In both cases the plants operate at close to 90% of capacity during the year, and in both cases they are able to shut down to refuel, service and bring those plants back up to operate in about 20 days. They use different technologies from different vendors in different regions.

In Switzerland they have PWRs from Westinghouse and Siemens, and BWRs from General Electric. They also operate at very high capacity, despite the plants being from different vendors, built by different architect-engineers, and with experience of each being operated by a different independent private utility. Yet they also, year after year, operate well. So, my contention is that it is not the technology, whether standard or non-standard, that leads to good performance; it is something else—appropriate management. We can argue about what constitutes appropriate management, but we know it when we see it. That is my summary of what I have heard this morning.

Prof. Michael Golay (MIT):

We will hear from Prof. Hansen again in about three more sessions, and I thank him deeply for his efforts to this stage of our Conference. For our last session today we are going to consider renewable energy technologies. The inspiration for this session is Prof. Socolow, who during our last Conference made one of the more memorable remarks. Paraphrasing, he said:

> "I look around and I see a room full of mostly middle-aged men who are very much enamored with one technology, but who are considering it outside the context of other technologies. I suggest the proper question to address is that of what role should nuclear power play in the context of all of the energy technologies one might consider."

The set which is most important for that consideration is that of the renewable energy technologies. In reality the term is a little misleading. This is because some of these technologies are not truly renewable. However, the term will serve.

What I want to accomplish in this session is to provide a clear statement of the promise of those technologies. It is clear that some of them are improving significantly and are likely to play an important role in the overall energy scene. In addition to competing with the traditional fossil fueled technologies, nuclear power, in the long run, is going to have to be able to make the case that it is competitive against the renewables if it is still to retain an important role. This is especially true if the fact which opens the opportunity for the future use of nuclear technology is concern over global warming. So, we are very lucky today to have Dr. Robert Williams from the Center for Energy and Environmental Sciences at Princeton University. The respondent paper will be offered by Prof. Lidsky and Dr. Cohn. First, we turn things over to Dr. Williams.

SESSION FOUR

WHAT ROLE SHOULD RENEWABLE ENERGY TECHNOLOGY PLAY, AND WHAT WOULD LIFE BE LIKE WITH THEM?

THE OUTLOOK FOR RENEWABLE ENERGY

Robert H. Williams

Princeton University

RESPONSE:

WHAT NOW? AN EXAMINATION OF THE IMPACT OF THE ISSUES RAISED

Lawrence M. Lidsky
and
Steven M. Cohn

Massachusetts Institute of Technology
and
Knox College, Galesburg, IL

INTRODUCTION

Session 4 – What Role Should Renewable Energy Technology Play, and What Would Life Be like With Them?

Renewable energy technologies and energy end-use efficiency improvements (so-called energy conservation) are sometimes cited as alternatives to fossil and nuclear fueled technologies. It is often argued that if only the renewables and conservation technologies were developed to their potential, then it would be feasible to dispense with fossil fuels and nuclear power technologies. These arguments have been used as justification for blocking the use of nuclear power. Critics have attacked these arguments as being wishful thinking, or simply unjustified hopes, that the grass would be greener on the other side of the fence. To some extent it is always attractive to yearn for a reality different from the current one, even when the feasibility of that alternative may be doubted.

Because the alternative energy technologies appear likely to play such a large role in affecting the future of nuclear power we decided to include a session in the Conference to provide an opportunity for a strong argument to be made in favor of them. The topics examined include the mix of technologies being pursued currently, assessments of their prospective roles in the energy economy and their remaining development requirements, their important uncertainties and the implications of their widespread use.

This assessment is important in formulating a well-founded future energy plan. If the prospects for these technologies is promising, then reasonable people can argue that life without nuclear power might be worth living; if these prospects are poor then opposition to nuclear power looks more like a flight from reality.

THE OUTLOOK FOR RENEWABLE ENERGY

Robert H. Williams

The oil shocks of the 1970s created substantial public interest in alternative energy sources generally and renewable energy in particular. The political interest in renewables was reflected in U. S. federal funding for R&D on a wide range of renewable energy technologies, with federal expenditures rising from $506 million in 1977 to a peak level of $1110 million in 1980 (1992 dollars). With the decline in the world oil price and a shift to *laissez faire* energy economics in the 1980s, public sector interest in renewables waned, and the R&D budget for renewables collapsed to $479 million by 1982 and to $116 million by 1990 [1,2].[1]

Despite the relative lack of federal support for R&D on renewables, impressive technical gains have been made for many renewable energy technologies. Some advances took place within the renewable energy sector. For example, tax and utility regulatory policies favorable to renewables led to the installation of more than 15,000 wind turbines and their integration into existing electric utility grids in California, accompanied by a three-fold reduction in the busbar cost of wind energy between 1985 and 1990 (see Figure 4.1).[2] And even though federally supported R&D on photovoltaics fell from $255 million in 1980 to less than $40 million in 1990 (in 1992 dollars) before it started rising again and photovoltaic (pv) prices are still far from levels where pv technology can compete in large-scale markets, technological progress has been rapid. Pv module prices have fallen (in 1992 dollars) from about $50 per W_p in 1976 to $6 per W_p in 1992 (see Figure 4.2), and the prospects for another order of magnitude reduction in costs via development and commercialization of advanced concepts such as various thin-film technologies (see Figure 4.3) are good. In addition, renewable energy systems have benefited from developments in electronics, biotechnology, materials sciences, and in other energy areas. For example, advances in jet engines for military and civilian aircraft applications, and in coal gasification for reducing air pollution from coal combustion, make it possible to produce electricity competitively using gas turbines derived from jet engines and fired with gasified biomass.[3] And fuel cells developed originally for the space program have opened the door to the use of hydrogen as a non-polluting fuel for transportation. Indeed, many of the most promising options are the result of advances made in areas not directly related to renewable energy and were scarcely considered a decade ago.

Today there is a resurgent public interest in renewable energy, in light of both the dramatic progress that has been made in renewable technologies and the promise offered by renewables in coping with a much wider set of societal concerns about externalities associated with the energy system (see Box A) than the concern about energy security that dominated energy policy-making in the 1970s. These concerns led to the commissioning of a major review of the prospects for producing electricity and fuels from renewable energy sources by the United Nations Solar Energy Group on Environment and Development, as an input to the 1992 United Nations Conference on Environment and Development in Rio de Janeiro. This review, carried out by more than 50 renewable energy specialists from 11 countries was published as the book *Renewable Energy: Sources for Fuels and Electricity* [4] in early 1993.

In the overview chapter [5] of *Renewable Energy*, the book's editors constructed a Renewables-Intensive Global Energy Scenario (RIGES) looking to the years 2025 and 2050, based on the findings for the individual renewable energy technologies. Scenarios for energy demand were not constructed anew for this exercise. Rather, one of the global energy demand scenarios constructed by the Response Strategies Working Group (RSWG) of the

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1 The relative decline in federal R&D support for renewables was much sharper than for nuclear fission, for which federal R&D fell from $3143 million in 1980 to $572 million in 1990 (1992 dollars) [2].

2 All costs in this paper are expressed in constant 1992 dollars. Electricity costs are calculated assuming electric utility ownership and llifecycle cost accounting rules recommended by the Electric Power Research Institute [3]. For wind turbines, assumed to have 25-year lifetimes, the annual capital charge rate is 10.7% per year.

3 The term "biomass" refers to any plant matter used directly as fuel or converted into electricity or fluid fuels. Sources of biomass are diverse and include the wastes of agricultural and forest-product operations as well as woody or other plants grown specifically as an energy crop.

TREND IN COST OF ELECTRICITY FROM WIND

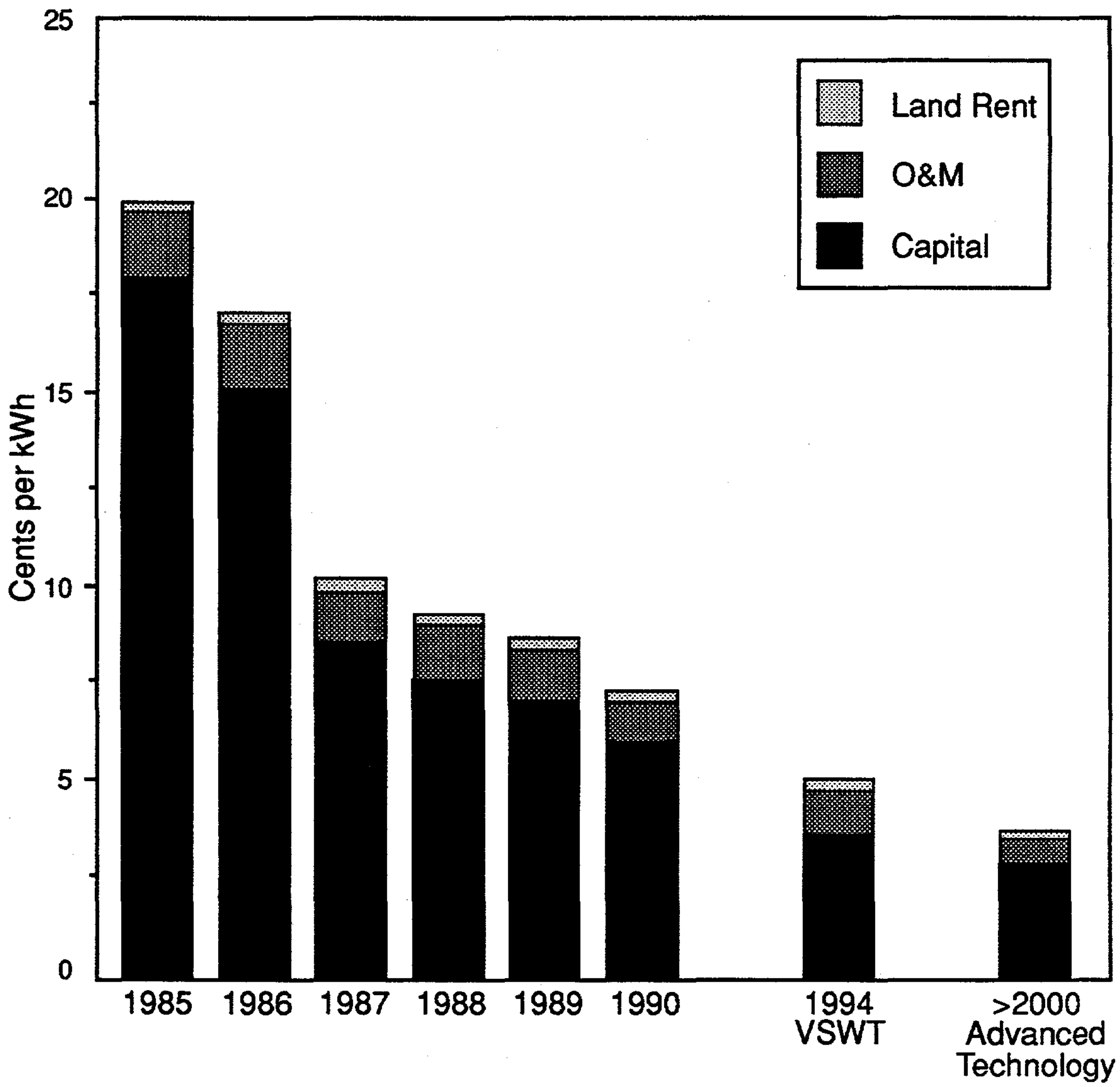

Figure 4.1: Trend In Cost Of Electricity From Wind Power In California.

Wind power costs for the period 1985-1990 are based on actual experience with wind farms in California. The cost shown for 1994 is for a new variable-speed wind turbine (VSWT) expected to go into commercial service in 1994, and for the period beyond 2000 the cost reflects expectations about improvements that could be realized over the next decade.

The cost of electricity from units expected to be in service by 1994 would be about the same as for a modern coal plant.

Intergovernmental Panel on Climate Change (IPCC) was adopted for this exercise—specifically the projections of demand for electricity and the direct use of gaseous, liquid, and solid fuels, desegregated by world region, for the high economic growth/high energy efficiency scenario of the 1990 IPCC renewable energy supplies matched to these demand levels for the years 2025 and 2050, consistent with estimates of natural resource endowments and expected relative prices. The purpose of the exercise was not to forecast how a renewables-intensive energy future would evolve, but rather to see how it might evolve with appropriate

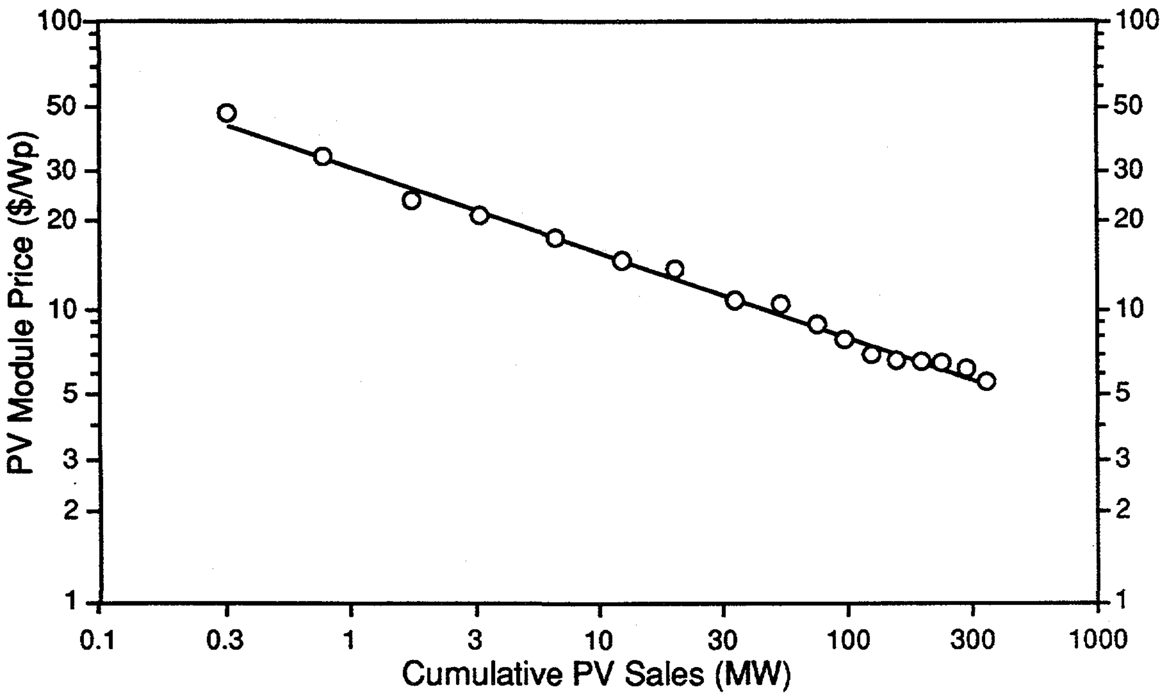

Figure 4.2: Log-Log Plot Of The Selling Price Of PV Modules, 1976-1992.

The pv module selling price follows closely an 81.6% experience curve. Module sales data and prices are from Strategies Unlimited, Mountain View, CA, September 1993. Strategies Unlimited used the Consumer Price Index to convert current prices into 1992 prices.

policies if society should study [6].[4] For each world region the book's editors constructed mixes of conventional and decide a renewables-intensive energy future is desirable. In constructing the scenario it was assumed that renewable technologies would capture markets whenever: (i) a plausible case can be made that renewable energy is no more expensive on a life-cycle cost basis than conventional alternatives,[5] and (ii) the use of renewable technologies at the levels indicated will not create significant environmental, land use, or other problems. The economic analysis did not take into account any credit for the non-market benefits of renewables listed in Box A. However, it was assumed that market barriers to the wide adoption of renewable energy technologies would be removed by aggressive national policies (e.g., see [7] for a

[4] The Response Strategies Working Group developed several projections of energy demand [6]. The one adopted for the renewables-intensive global energy scenario (RIGES) is characterized by "high economic growth" and "accelerated policies." The accelerated policies case was designed to demonstrate the effect of policies that would stimulate the adoption of energy-efficient technologies without restricting economic growth. Because renewable technologies are unlikely to succeed unless they are a part of a program designed to minimize the overall cost of providing energy services, the energy-efficiency assumptions underlying the accelerated policies scenario are consistent with the objectives of the renewables-intensive scenario.

The high economic-growth, accelerated-policies scenario projects a doubling of world population and an eight-fold increase in gross world economic product between 1985 and 2050. Economic growth rates are assumed to be higher for developing countries than for the already industrialized countries. Energy demand grows more slowly than economic output, because of the accelerated adoption of energy-efficient technologies, but demand growth outpaces efficiency improvements—especially in rapidly growing developing countries. World demand for fuel (excluding fuel for generating electricity) is projected to increase 30% between 1985 and 2050 and demand for electricity 265%.

[5] Since the purpose of the RIGES was to explore the potential offered by renewables to meet developmental, environmental, and security challenges posed by the energy system, the role of nuclear power was assumed to be limited to the present level, about 1800 TWh/year worldwide.

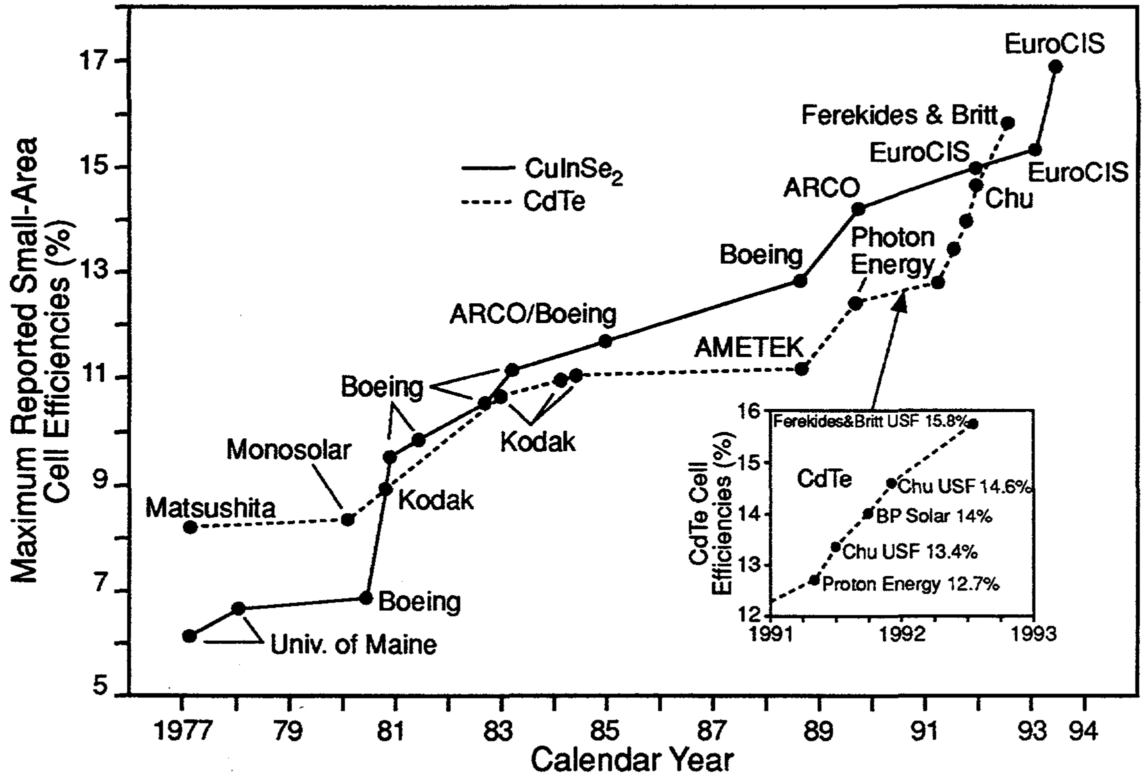

Figure 4.3: Stabilized Efficiencies Of Small-Area Polycrystalline Thin-Film Photovoltaic (PV) Cells. Values Are Shown For Both Copper Indium Diselenide ($CuInSe_2$) And Cadmium Telluride (CdTe).

Thin-film pv devices offer the potential for realizing very low unit capital costs at moderate efficiencies. (Other kinds of pv devices have the potential for realizing higher efficiencies but at higher unit capital costs.) The potential for low unit capital cost arises because the active layers of the cells are of the order of one micron thick and thus require very little material. (Note that a typical human hair is about 90-100 microns thick.) Thus the materials cost is dominated by the costs for glass for encapsulation, wires, etc.

The efficiencies shown in this figure are for laboratory cells (areas of the order of 1 cm^2). Further development is needed in order to realize a 15% efficiency in large modules (of the order of 1 m^2 or more per module) and to engineer the processes for mass producing such devices. It is expected that, with an aggressive R&D effort, this could be realized by 2010.

These data, from Ken Zweibel, Manager of the Thin-Film Project, National Renewable Energy Laboratory, September 1993, are based on both NREL measurements and measurements reported in the literature.

discussion of the kinds of measures that might be pursued to accelerate the development of photovoltaic technology).

Global primary energy requirements and electricity generation for the RIGES are shown in Figures 4.4 and 4.5, and primary energy requirements for the U.S. in the RIGES are shown in Figure 4.6. It was estimated that renewable energy could provide nearly 3/5 of global primary energy requirements by 2050, with biomass accounting for about 3/5 of total renewable energy (see Figure 4.4). The fraction of electricity generated by renewables would be about the same, *Box A: Benefits of Renewable Energy Not Captured in Standard Economic Accounts*

Reduced Air Pollution: Renewable energy technologies, such as methanol or hydrogen for fuel-cell vehicles, produce virtually none of the emissions associated with urban air pollution and acid deposition, without the need for costly additional controls.

Abatement of Global Warming: Renewable energy use does not produce carbon dioxide and other greenhouse emissions that contribute to global warming. Even the use of biomass fuels will not contribute to global warming: the carbon dioxide released when biomass is burned equals the amount absorbed from the atmosphere by plants as they are grown for biomass fuel.

Fuel Supply Diversity: There would be substantial interregional energy trade in a renewables-intensive energy future, involving a diversity of energy carriers and suppliers. Energy importers would be able to choose from among more producers and fuel types than they do today and thus would be less vulnerable to monopoly price manipulation or unexpected disruptions of supplies. Such competition would make wide swings in energy prices less likely, leading eventually to stabilization of the world oil price. The growth in world energy trade would also provide new opportunities for energy suppliers. Especially promising are the prospects for trade in alcohol fuels such as methanol derived from biomass, natural gas (not a renewable fuel but an important complement to renewables), and, later, hydrogen.

Reducing the Risks of Nuclear Weapons Proliferation: Competitive renewable resources could reduce incentives to build a large world infrastructure in support of nuclear energy, thus avoiding major increases in the production, transportation, and storage of nuclear fuels which could be diverted to nuclear weapons production.

Social and Economic Development: Production of renewable energy, particularly biomass, can provide economic development and employment opportunities, especially in rural areas, that otherwise have limited opportunities for economic growth. Renewable energy can thus help reduce poverty in rural areas and reduce pressures for urban migration.

Land Restoration: Growing biomass for energy on degraded land can provide the incentives and financing needed to restore lands rendered nearly useless by previous agricultural or forestry practices. Although lands farmed for energy would not be restored to their original condition, the recovery of these lands for biomass plantations would support rural development, prevent erosion, and provide a better habitat for wildlife than at present.

but biomass would provide less than 3/10 of renewable electricity (see Figure 5), while intermittent renewables (wind, photovoltaic, and solar thermal-electric sources) would provide about 3/10 of all electricity. For the U.S., renewables would contribute more than half of primary energy in 2050, more than half which would come from biomass (see Figure 6). For the U.S. nearly 2/3 of electricity would be provided by renewables in 2050, but less than 1/4 of renewable electricity would come from biomass.[6] If the RIGES could be implemented, global CO_2 emissions from the energy sector in 2050 would be reduced by 1/4 relative to 1985 emissions (see Figure 4), while U.S. emissions would be reduced by 3/4 (see Figure 6).

ADDRESSING COMMONLY HELD CONCERNS ABOUT RENEWABLE ENERGY

In this paper, key aspects of a renewables-intensive global energy future are discussed in the context of concerns that are often expressed about renewable energy. It is widely believed that:

1. Renewable energy costs are so far from levels needed for widespread adoption that renewables can contribute only very modestly to overall energy supplies over the next several decades.

[6] Biomass power generation for the U.S. in 2050 is about 500 TWh in the RIGES. For comparison, an EPRI study projects that biomass could potentially provide 50 GW_e of generating capacity (330 TWh/year) by 2010 and double that amount by 2030 [8].

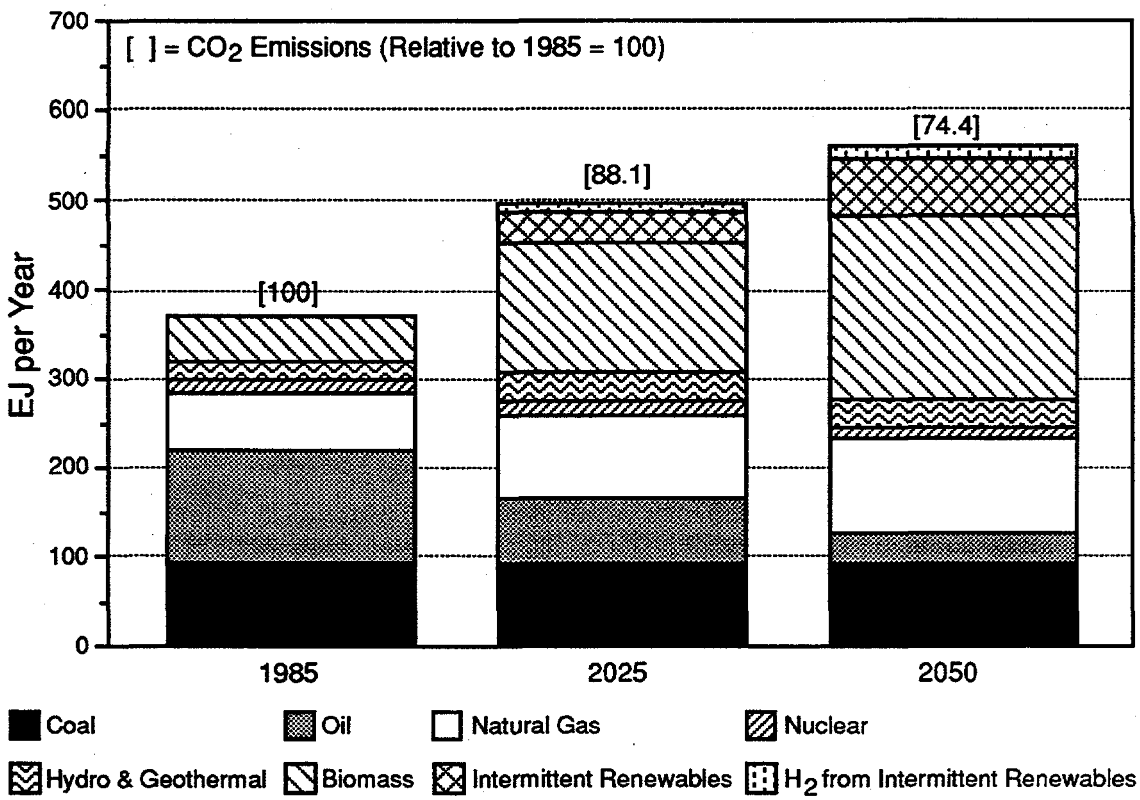

Figure 4.4: Global Primary Energy Requirements For The Renewables-Intensive Global Energy Scenario.

This figure shows global primary energy requirements for the renewables-intensive global energy scenario developed in [5] in an exercise carried out to indicate the future prospects for renewable energy for each of 11 world regions. In developing this scenario, the high economic growth/high energy efficiency demand projections for solid, liquid, and gaseous fuels and electricity developed by the Response Strategies Working Group of the Intergovernmental Panel on Climate Change [6] were adopted in [5] for each world region. For each region a mix of renewable and conventional energy supplies was constructed in [5] to match these demand levels, taking into account relative prices, regional endowments of conventional and renewable energy sources, and environmental constraints.

The primary energy associated with electricity produced from nuclear, hydroelectric, geothermal, photovoltaic, wind, and solar thermal-electric sources is assumed to be the equivalent amount of fuel required to produce that electricity, assuming the average heat rate (in MJ per kWh) for all fuel-fired power-generating units in a given year. This global average heat rate is 8.05 MJ per kWh in 2025 and 6.65 MJ per kWh in 2050.

For biomass-derived liquid and gaseous fuels the primary energy is the energy content of the biomass feedstocks delivered to the biomass energy conversion facilities.

Primary energy consumption in 1985 includes 50 EJ of non-commercial biomass energy [26]. It is assumed that there is no non-commercial energy use in 2025 and 2050.

2. Renewables can play only minor roles in electric power generation without major advances in electrical storage technology.

3. Roles for renewable energy will be sharply limited by the fact that the best renewable energy resources are often remote from energy demand centers.

4. Without the benefit of a stiff carbon tax, biomass cannot compete in either electric power or fluid fuels markets, because biomass feedstocks are inherently more costly than coal, which is abundant.

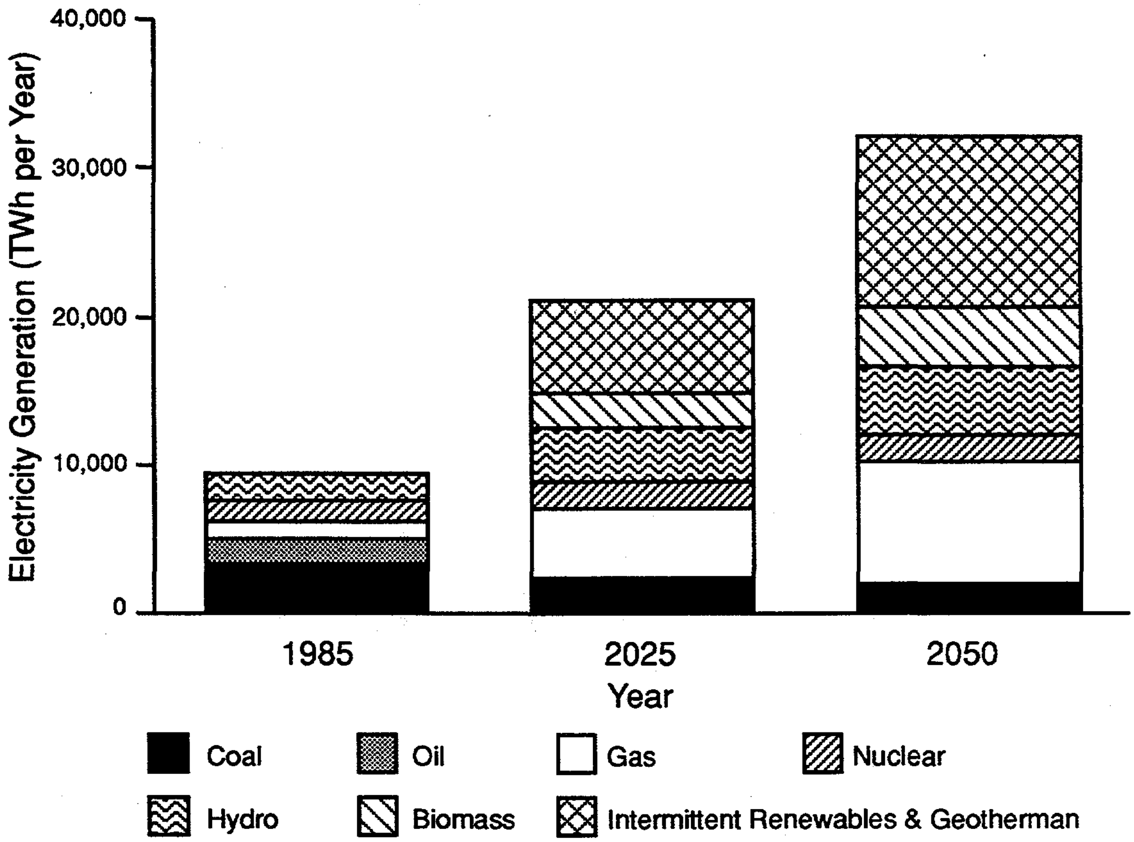

Figure 4.5: Electricity Generation For The Renewables-Intensive Global Energy Scenario.

In the global energy demand scenario [6] adopted for the RIGES [5], global electricity production would more than double by 2025 and more than triple by 2050. The share of renewables in electricity generation would increase from about 20% in 1985 (mostly hydropower) to more than 60% in 2025, with roughly comparable contributions from hydropower, intermittent renewables (wind, photovoltaic, and solar thermal-electric power), and biomass. The contribution of intermittent renewables could be as high as 30% by the middle of the next century.

A high rate of penetration of intermittent renewables without electrical storage would be facilitated by emphasis on advanced natural gas-fired gas turbine power-generating systems. Such power-generating systems, characterized by low capital cost, high thermodynamic efficiency, and the flexibility to vary electrical output quickly in response to changes in the output of intermittent power-generating systems—would make it possible to "back-up" the intermittent renewables at low cost, with little, if any, need for electrical storage. For the scenario developed here, the share of natural gas in power generation nearly doubles by 2025, from its 12% share in 1985.

5. Because its production is so land-intensive, biomass can make only marginal contributions to overall energy requirements.

6. Biomass energy poses serious environmental problems.

7. To achieve deep reductions in greenhouse gas emissions in a greenhouse-constrained world, both nuclear and renewable energy sources will be needed on large scales.

In what follows, each of these concerns is addressed in turn.

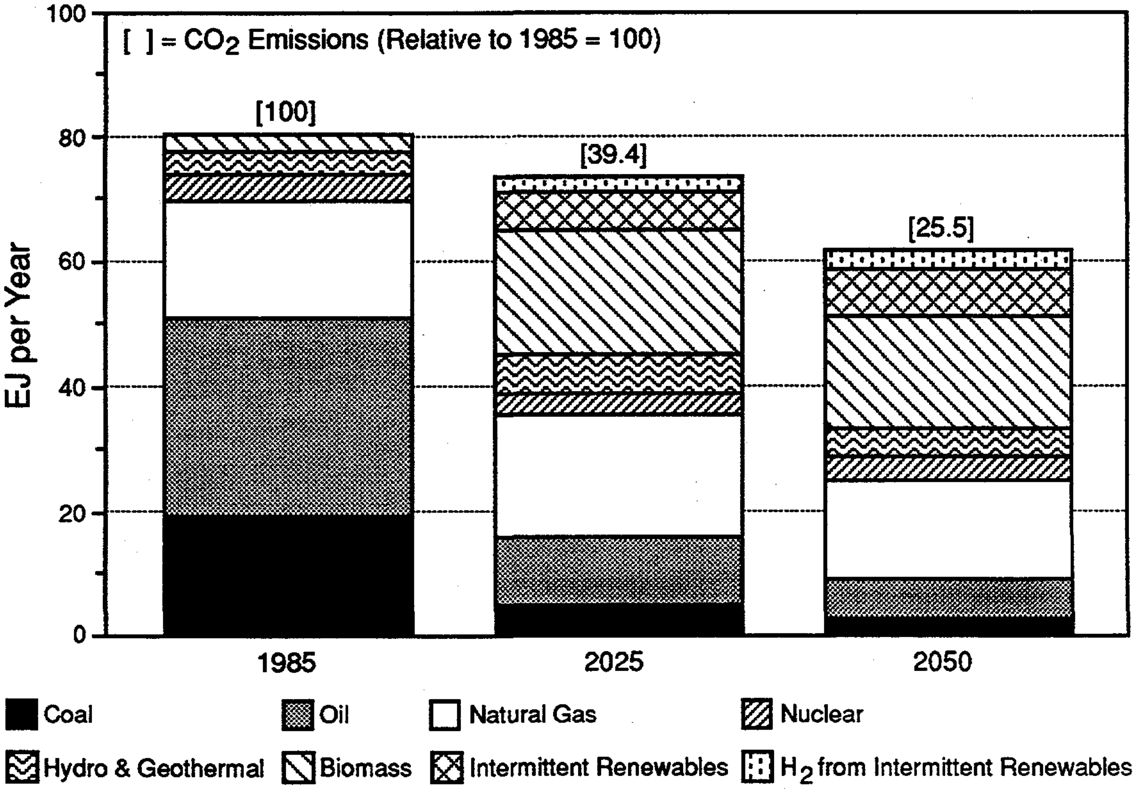

Figure 4.6: Primary Energy Requirements For The U.S. in the Renewables-Intensive Global Energy Scenario.

This figure shows primary energy requirements for the U.S. in the renewables-intensive global energy scenario developed in [5] in an exercise carried out to indicate the future prospects for renewable energy for each of 11 world regions, one of which is the U.S. In developing this scenario, the high economic growth/high energy efficiency demand projections for solid, liquid, and gaseous fuels and electricity developed by the Response Strategies Working Group of the Intergovernmental Panel on Climate Change [6] were adopted in [5]. For the U.S. and other industrialized countries, this demand scenario involves a slow decline in primary energy demand as the economy expands, as a result of the emphasis given to improved energy efficiency. The mix of renewable and conventional energy supplies shown was constructed in [5] to match these demand levels, taking into account relative energy prices, endowments of conventional and renewable energy sources, and environmental constraints.

The primary energy associated with electricity produced from nuclear, hydroelectric, geothermal, photovoltaic, wind, and solar thermal-electric sources is assumed to be equivalent to the amount of fuel required to produce that electricity, assuming the average heat rate (in MJ per kWh) for all fuel-fired power-generating units in a given year. The U.S. average heat rate is 8.07 MJ per kWh in 2025 and 6.42 MJ per kWh in 2050.

For biomass-derived liquid and gaseous fuels the primary energy is the energy content of the biomass feedstocks delivered to the biomass energy conversion facilities.

1. <u>Renewable Energy Costs Are So Far From Levels Needed For Widespread Adoption That Renewables Can Contribute Only Very Modestly To Overall Energy Supplies Over The Next Several Decades</u>

Renewable energy technologies are much closer to being able to compete in mass energy markets than most people think, both because costs have been declining quickly and because renewable energy will often be more valuable than conventional energy. The economic prospects for renewables are illustrated here by discussions of wind, biomass, and photovoltaic electric sources and of renewable fuels for fuel cell vehicles.

Outlook For Costs Of Electricity From Renewables

One of the major accomplishments relating to renewables in the 1980s is the rapid development of wind power and the dramatic reduction in wind power costs that took place in California (see Figure 4.1). There were problems with the early wind turbines, to be sure. Tax incentives encouraged rapid construction of wind turbines whose designs had not been rigorously tested, and failures were common--giving rise to the disparaging characterization of wind power as "tax-shelter energy investment." Since then most problems have been resolved.

Remarkably, few of the wind power cost reductions can be traced to improved technology. Except for lightweight composite-material blades and microprocessor-controlled turbines, until very recently most of the wind turbines that have been sold incorporated no substantial aerodynamic or design innovations over those built 50 years ago. Instead cost reduction has been achieved mainly from organizational learning, which involves standardizing procedures. At the factory, manufacturers learned mass production techniques; in the field, workers learned to site turbines so as to better exploit the local wind resource and to schedule maintenance for times of low wind.

The small unit size (50 to 300 kW_e) and relative simplicity of wind and many other renewable energy technologies facilitates cost-cutting. Most renewable energy equipment can be constructed in factories, where it is easier to apply modern manufacturing techniques that facilitate cost reduction. The small scale of the equipment also makes the time required from design to operation short, so that needed improvements can be identified by field testing and quickly incorporated into modified designs. As a result of such learning by doing, many generations of marginal technological improvements can be introduced in short periods.

In contrast, large conventional nuclear and fossil fuel energy facilities require extensive construction in the field, where labor is costly and productivity gains difficult to achieve. The long construction periods for these large energy systems also make learning difficult. In the 1970s and 1980s production bottlenecks arising from the practical difficulties of standardizing designs for large energy production facilities, toughening environmental regulations, and growing public opposition to the construction of new facilities often meant that energy produced by new plants was more costly than energy from old plants. In the case of nuclear power these problems were well understood 20 years ago, as articulated in an insightful analysis by John Fisher (see Box B), then Manager of Energy Systems Planning for General Electric's Power Generation Business Group, who predicted in 1974 [9]:

> "Advocates of fossil fuel may tend to hope that one 50% increase in nuclear plant construction costs will be followed by others and to project much higher nuclear plant costs in the future; but I believe this view is mistaken. The field construction cost lesson appears to have been learned, and there is an increasing trend toward standardization and assembly line construction of major nuclear power plant components. The requirements of the new licensing procedures are being better anticipated now that they are more familiar, and licensing delays may diminish. Overall, competition between nuclear power and fossil fuel power is likely to remain vigorous."

But apparently, Fisher's early warnings were largely ignored by the nuclear industry until after its collapse.

In the case of wind power we are only now beginning to see the benefits of technological innovation. One innovative machine that is just coming onto the market is the variable speed wind turbine (see Figure 4.1), which makes it possible for the rotor to turn at optimal speed under a wide range of wind conditions, thereby increasing wind energy capture, while also reducing material fatigue, and reducing maintenance costs. Busbar costs for this new technology are about 5 cents per kWh in areas having good wind resources—about the cost of electricity from a new coal plant. This technology has been brought to commercialization by U.S. Windpower for a total development cost of $70 million. The technology was advanced via joint venture involving the Pacific Gas and Electric Company, the Niagara Mohawk Company, and the Electric Power Research Institute. The astonishingly low development cost can be attributed largely to: (i) the simplicity and modularity of the technology, and (ii) the fact that costs for variable speed drive technology fell dramatically in the 1980s as a result of

Box B: The Roots of Nuclear Power Cost Escalation

A 1974 analysis by John Fisher [9] of the escalation in nuclear power costs in the decade leading up to the first oil crisis provides an important insight relating to power plant construction-related problems that seems relevant for the escalation in electric power costs generally from 1970 to the mid-1980s:

> "When measured in constant dollars per kilowatt of capacity, the cost of constructing a nuclear power plant increased by perhaps 50% in the past decade... When power plant costs rise an explanation is required, as we expect all power plant costs to decline through the economies of scale and new technology. The environmental movement was responsible for part of the rise in nuclear plant costs, by causing various procedural delays and by requiring additional expensive safeguards to protect against hypothetical accidents. But there appears to be another cause for increasing construction costs, associated with a growing portion of high-cost field construction and a shrinking proportion of low-cost factory construction for the very large power plants now being built... The costs associated with a shift to field from factory can more than offset anticipated economies of scale..."

Fisher pointed out that for many decades plant construction in the electric power industry followed a pattern in which part of the construction (mainly the building and the boiler) was carried out in the field and part (manufacture of the turbine, generator, and power conditioning equipment) was carried out in large factories serving many utility plants. As electric utility plant capacity doubled every decade, factory capacity also doubled, as did field construction at each site. Manufacturing and construction costs per kW_e declined in the factory and in the field, since each of these increased its scale of operations. As long as both activities grew in proportion, the economies of scale produced similar cost reductions in each, and therefore an overall cost reduction, even though the unit cost of field construction was always higher than the unit cost of factory construction. This pattern held until plant size reached about 200 MW_e and was reflected in a good fit of the average U.S. electricity price to a 75% experience curve during most of the period up to 1970 (see Figure 4.7).

This trend was upset with the introduction of nuclear power. Because of the requirements for shielding and containment and other specifically nuclear features, nuclear plants were expected to be more capital-intensive than fossil fuel plants for the same rating. Since these nuclear-related costs account for a smaller fraction of the total cost at larger plant sizes, it was reasoned that nuclear plants must be built large. Accordingly, nuclear power plant capacities were built in sizes of the order of 1000 MW_e. But building larger plants requires shifting a larger fraction of total construction from the factory to less-efficient field locations, thereby raising costs.

Fisher's important insight is that the widely touted economies of scale in power plant construction are illusory because: (i) field construction is inherently more costly than factory construction, and (ii) with field construction it is never possible to move very far along the learning curve, in contrast to the situation with factory production.

rapid growth in markets for variable speed drives for ac induction motors in commercial building and industrial applications. Variable speed drive costs have fallen to the point where it has become economically attractive to adapt the technology to wind power. Further technological improvements are expected to reduce the cost of wind power to 4 cents per kWh or less over the next decade or so (see Figure 4.1).[7]

[7] One prospective improvement involves the designing the airfoils specifically for use in wind turbines instead of relying on blades adapted from airplanes. Another involves increasing turbine hub heights to gain access to better wind resources. Over smooth terrain in the Great Plains (the location of over 90% of exploitable U.S. wind energy potential), wind speeds typically increase with height by the one-seventh power of the height, so that increasing the height from 30 m (typical of new installations today) to 50 m increases the wind power density by 1/4; also, the wind tends to be much steadier at higher heights [10,11].

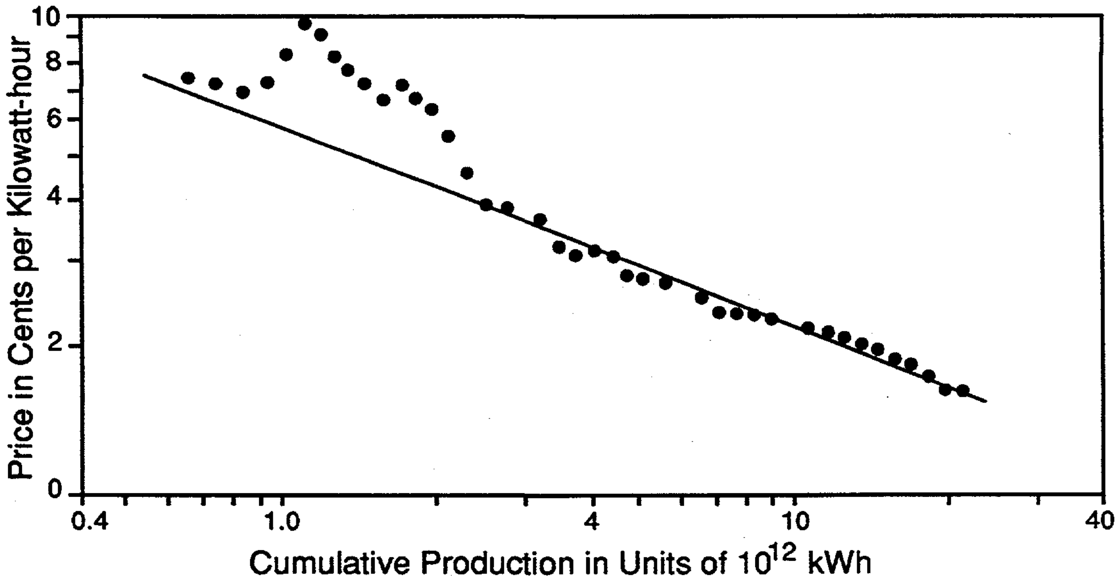

Figure 4.7: The Trend For U.S. Electricity Prices (in 1970 cents/kWh) From 1926 To 1970.

The trend line corresponds to a 75% experience curve—i.e., the average price fell 25% for each cumulative doubling of production in this period. Prices rose above the trend line in the 1930s largely because of the high fixed charges associated with electricity generation in the face of depression-diminished demand [9].

Biomass power plants will typically have capacities in the range 25-100 MW_e. Because of the relatively low energy densities of biomass compared to coal and thus the high cost of transporting biomass long distances, biomass power plants will be much smaller than fossil fuel and nuclear plants. Thus conversion technologies characterized by low unit capital cost and high thermodynamic efficiency at modest scales are needed. One such technology being developed is a set of biomass-integrated gasifier/gas turbine (BIG/GT) designs that marry an airblown gasifier (adapted from coal-gasification efforts) to a variety of high efficiency gas turbine cycles such as gas turbine/steam turbine combined cycles and intercooled steam-injected gas turbines that offer an overall energy conversion efficiency of over 40%—twice the efficiency of commercial biomass power plants, which are based on the steam Rankine cycle [12]. Fueled with biomass grown on plantations having a productivity of 15 dry tonnes per hectare per year, such plants would require about 2 km^2 of land area per MW_e.

Field tests in southern Sweden are underway for a 6 MW_e pilot plant for one variant of BIG/GT technology, and a 30 MW_e commercial-scale demonstration plant is being planned for the late 1990s in the northeast of Brazil, with a $30.7 million grant from the Global Environment Facility of the World Bank. This plant would use as fuel wood chips from trees grown in plantations established on degraded lands [13]. The overall cost of this first-of-a-kind demonstration is expected to be $60 to $70 million, with the rest of the funding provided by the equity partners and by loans.

A Shell study projects that the installed cost of the tenth plant of this type will be $1300 per kW_e (see Figure 4.8, based on the expectations that: most plant assembly would take place in the factory; there would be minimal site preparation and foundation requirements; on-site construction would consist mainly of integration of standard factory-built modules, and there would be short time lapses between ground breaking and plant start-up [13]. In addition, an Electric Power Research Institute study projects that the cost of biomass grown on plantations in the U.S. and transported 25 miles to the conversion facility will cost in the year 2010 time frame $2.2 to $2.4 per GJ (HHV basis), net of biomass loses and including the cost of crop

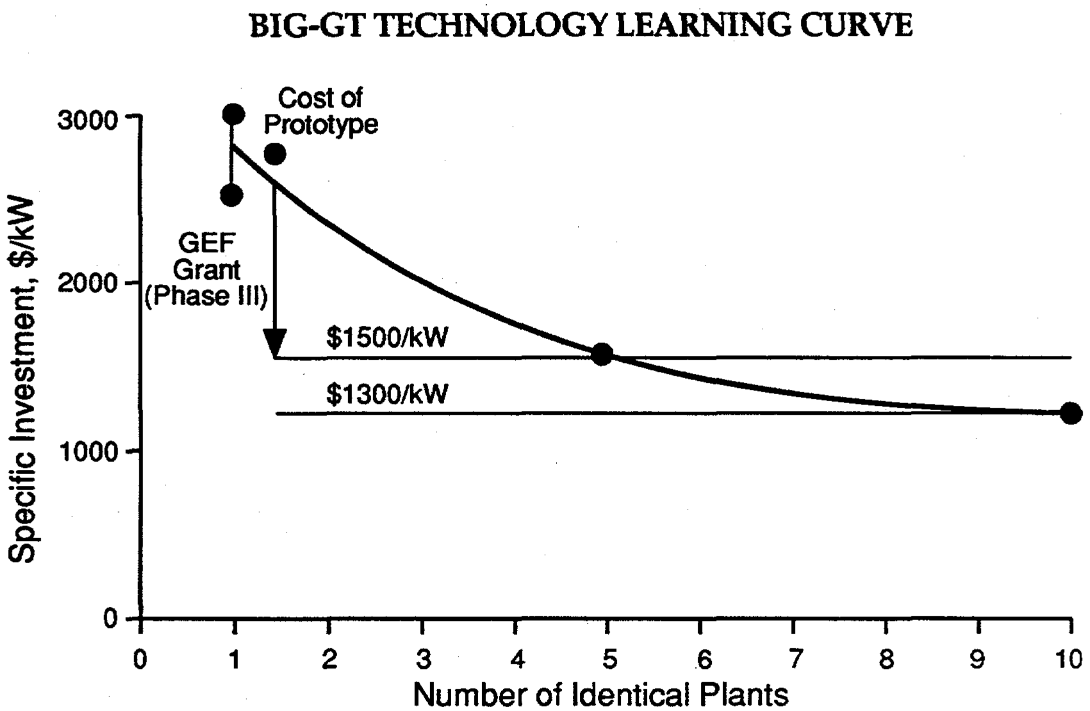

Figure 4.8: Learning Curve For Biomass-Integrated Gasifier/Gas Turbine Technology.

This learning curve indicates the expected trend in unit costs for power plants based on the biomass-integrated gasifier/gas turbine (BIG/GT) technology that will be demonstrated in Brazil in the late 1990s with support from the Global Environment Facility—a 25 MW_e gas turbine/steam turbine combined cycle coupled to an air-blown biomass gasifier. Shell researchers project that the costs for the first ten units will follow a learning curve characterized by an 80% progress ratio (i.e., the installed cost is expected to decline 20% for each cumulative doubling of production), based on the expectations that: most plant assembly would take place in the factory; there would be minimal site preparation and foundation requirements; on-site construction would consist mainly of integration of standard factory-built modules; and there would be short time lapses between ground breaking and plant start-up [13].

insurance to cover bad growth years [8]. The corresponding busbar cost for plants operated at 75% capacity factor would be less than 5 cents per kWh, so that the system is expected to be competitive with coal and nuclear power in many instances. Costs of plantation biomass would tend to be much less in developing countries, where labor costs are much lower (biomass production is very labor intensive), and growing seasons are often longer [14].

A comparison of expected BIG/GT "learning costs" with those for larger scale energy technologies is instructive. For a given technology costs tend to vary not simply with calendar time but rather as a function of cumulative production, according to:

$$c(x) = a \cdot x^{\left(\frac{\ln PR}{\ln 2}\right)}$$

where

- c(x) = cost of producing the x^{th} unit of output,
- x = cumulative production, between the 1^{st} and x^{th} unit,
- a = cost of producing the first unit, and
- PR = the progress ratio,[8] a measure of cost reduction, as cumulative production increases.

[8] A progress ratio of 0.8 (often expressed as a percent—i.e., an 80% progress ratio) implies that costs fall 20% for each cumulative doubling of production.

For a 25 MW_e BIG/GT plant, the learning costs (i.e., the costs in excess of \$1300/kW_e for the first ten plants) amounts to about \$0.12 billion, if, as projected by Shell, production follows an 80% learning curve, which is typical of a wide range of dynamic industries [7].

In light of the poor track record in learning of the nuclear industry (see Box B), some might argue that one would not see this kind of learning if a new nuclear reactor concept were introduced. But suppose that the nuclear industry were to introduce a new, acceptably safe, 600 MW_e "modular" nuclear technology for which the cost per kW_e for the first unit is the same as that expected for the Brazilian BIG/GT demo, and that learning takes place at the same rate as is being projected for the Brazilian BIG/GT technology—i.e., following an 80% progress ratio. In this case the learning cost for the first ten plants would be 24 times greater—some \$2.9 billion.

The highly modular nature of photovoltaic technology implies that even for this technology, which has much further to go before it is competitive in mass energy markets, the effort required for future research and development and market stimulation to bring costs down to competitive levels is likely to be a tiny fraction of the subsidies that have been provided for nuclear fission. Specifically, an analysis has been carried out showing that: (*i*) a worldwide effort to accelerate the development of pv technology to the extent that 400 GW_e of pv capacity would be installed in grid-connected, distributed configurations by 2020 could probably be accomplished with \$5 billion[9] of government subsidies for market stimulation efforts plus an additional \$13 billion in government R&D support,[10] if historical trends in pv cost reduction were to persist (e.g., pv module costs continue to be characterized by an 81.6% progress ratio—see Figure 4.2); (ii) such an effort would probably lead to more than a \$60 billion reduction in consumer expenditures on electricity for all distributed grid-connected pv systems installed worldwide in the period 1995-2020; and (iii) there are good prospects that the pace of cost reduction would be faster than the historical rate at the assumed level of R&D effort, so that the societal costs would be less than these estimates, and the societal benefits (measured as net reduced consumer expenditures on electricity) much more. The World Energy Council has also estimated what it will take to develop and commercialize pv and various other renewable technologies. In the case of pv, the Council estimated a market stimulation cost of \$2.5 to \$4.0 billion, plus another \$5 billion for R&D; the Council estimated the total cost of development for a set of various renewable energy technologies to be in the range of \$15 to \$20 billion [32]. For comparison, governments of OECD countries spent about \$100 billion (in 1992 \$) on nuclear fission energy R&D, 1977-1991 [1,2], and probably at least twice that much in total, if one also includes R&D expenditures from the period 1950-1976.[11]

The Value Of Electricity Produced In Small-Scale Generators

The modest sizes for most renewable energy equipment also implies added value in some instances. Whereas the economics of larger plants depends heavily on long-term forecasts, which have proven notoriously unreliable, small plants can be added quickly as they are needed and even disassembled and moved if loads decline. The uncertainty inherent in any demand forecasting is increased by new programs to encourage investment in energy efficiency and non-utility generation—programs whose outcomes are difficult to predict with precision.

In addition, the reliability of the electric power generation system can often be increased by installing a large number of small generators instead of a few large ones. A utility must maintain reserves sufficient to cover an unexpected failure of its largest operating plant. The reserve capacity required to meet the "one-day-in-10-years" loss-of-load reliability criterion is higher for a set of large plants than for a larger number of smaller plants with identical failure rates per plant.

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9 The future subsidies for market stimulation and pv R&D are presented here as the worth in 1995, assuming a 6% discount rate.

10 A six-fold increase of the 1991 rate of industrialized country support of \$198 million per year [2], through 2013.

11 Total U.S. expenditures on nuclear fission R&D amounted to \$24 billion, 1977-1991 [1,2] and \$56 billion over the entire period 1950-1993 [15].

Electric generators that can be built in small sizes also change the logic of investments in electric transmission and distribution. Traditionally, investments in transmission and distribution networks have been justified: (i) to aggregate loads to take advantage of large-scale generation (and its presumed lower cost power), (ii) to create load diversity so that generators need not follow the sharp variations in demand for individual customers, and (iii) to increase reliability by interconnecting many different thermal-electric plants and connecting remote hydroelectric generators to the system. In some instances investments in distributed renewables would be preferable to increased investments in transmission and distribution. Recent studies of the value of distributed photovoltaic systems in northern California [16,17,18] suggest that any system capable of reducing the demand on electrical transformers and associated transmission and distribution equipment at a utility substation can postpone the need for investment to expand the capacity of this load-bearing equipment. Such distributed siting will also reduce line losses and improve a utility's ability to control the quality of its power. In addition, distributed generators provide more options for routing power around faults in the distribution system and thus improve the reliability of electrical service. This reliability gain is important since the loss-of-load actually experienced by utility customers is typically several times as large as the one-day-in-10-years loss-of-load criterion used as a reliability standard for power generation by many utilities. Taken together, such benefits from photovoltaic systems appropriately sited in distributed configurations near consumers make it possible for photovoltaic power to compete in large electric grid-connected applications years before it could compete in central station power markets [7].

Outlook For Costs And Value Of Transportation Fuels From Renewables

It will be much harder to bring the costs of renewable fuels for transport markets down to the price levels for petroleum-derived fuels, unless future oil prices rise to very high and improbable levels over the next several decades. However, if urban air quality concerns lead to the introduction of the fuel cell as a competitor to the internal combustion engine (which could be an outcome of the Clinton Administration's Partnership for a New Generation of Vehicles with U.S. auto manufacturers), renewable fuels may well be able to compete *on a life-cycle cost basis* even at fuel costs that are much higher than the prices of petroleum-derived fuels [19]. This prospect arises as a result of the facts that: (i) fuel cell vehicles will be 2 1/2 to 3 times as energy-efficient as the internal combustion engine vehicles they would displace and will require less maintenance; and (ii) if, as seems likely, only low-temperature fuel cells (e.g., the proton-exchange-membrane fuel cell) will be used in light-duty vehicles, then the choice of energy carriers will be limited to hydrogen and those hydrogen carriers (i.e., methanol) that can be easily transformed into hydrogen via reforming onboard the vehicle. The least costly way to produce hydrogen or methanol from renewable energy sources is via thermochemical gasification of biomass, for which final consumer prices (pump prices) in the U.S., in $ per GJ, are likely to be 40-60% higher than the retail price of gasoline derived from crude oil costing $25 per barrel (see Figure 4.7) [19]. Despite the high fuel price, it is reasonable to expect that the cost of owning and operating a fuel cell vehicle, in cents per kilometer, would be less than the cost of operating an internal combustion engine vehicle on gasoline derived from crude oil priced at $25 per barrel (see Figure 4.9) [19].

2. <u>Renewables Can Play Only Minor Roles In Electric Power Generation Without Major Advances In Electrical Storage Technology</u>

It is widely believed that without substantial advances in electrical storage technology, renewables will be able to play only minor roles in electricity generation because of the intermittent nature of wind and direct solar resources. Indeed, in a major 1990 study carried out for the Department of Energy by the national laboratories to assess potential contributions from renewables to U.S. energy supplies to 2030, it was assumed that intermittent renewables would not be able to provide more than 20% of total installed electrical capacity in this period [24]—which implies a maximum of about 10% of total electricity generation in light of the lower capacity factors for intermittent renewables [20].

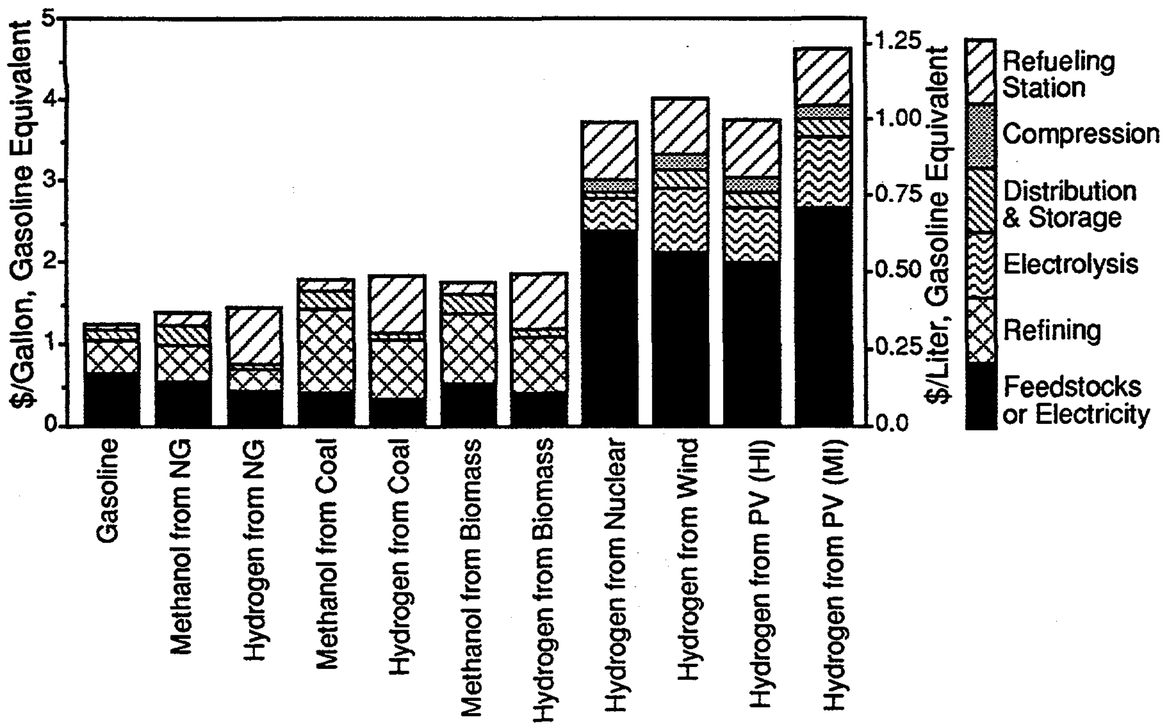

Figure 4.9: Costs for Alternative Fuels Delivered to Consumers in $ per Liter ($ per Gallon) of Gasoline-Equivalent.

Here NG = natural gas; PV = photovoltaic electricity; HI = in an area of high insolation (2400 kWh per m^2 per year), typical of the Southwest of the U.S.; MI = in an area of moderate insolation (1800 kWh per m^2 per year), the average insolation in the U.S. The details of the construction of these cost estimates are presented in [19].

Since the cost of hydrogen or methanol produced from biomass would be about the same as from coal, and the cost of electrolytic hydrogen would be about the same for renewable and nuclear sources, the choices between biomass and coal feedstocks for producing hydrogen or methanol and between renewable and nuclear options for producing electrolytic hydrogen can be made largely on the basis of considerations of externalities rather than direct costs.

There are practical limits on the potential contributions of intermittent renewables, because these resources are not dispatchable; without storage they can provide electricity only on Mother Nature's schedule. However, one should be skeptical about assigning arbitrary limits to the penetration of intermittent renewables. Direct solar resources are often well correlated with peak electrical demand in areas with large air conditioning loads. Some windy areas, particular warm coastal areas, have seasonal and daily patterns that correlate with demand, whereas others have winds that do not.

To understand better what the actual limits are, Kelly and Weinberg developed an electric utility simulation model for the UNCED renewable energy study [20]. This SUTIL (for Sustainable UTILity) model calculates the cost of electricity generation as the result of an hour-by-hour simulation that takes into account electricity demand, the variable output of intermittent renewable equipment, the load-leveling capabilities of hydroelectric facilities, and the dispatching characteristics of alternative kinds of thermal-electric generating plants. During each hour of the year, the output of intermittent renewable sources is subtracted from the total load (i.e., intermittent renewables are treated as "negative load"), and the model determines the least-costly way to serve the loads not covered by intermittents, within specified constraints.

The results of runs of the model carried out for the Pacific Gas and Electric (PG&E) Company's hourly load profile and solar and wind resource availability[12] are shown in Figure 4.10 for alternative portfolios of generating equipment that come on line in 2010. The graph shows that costs do tend to rise with the level of penetration but not by much. The average cost of electricity for the case (bar 8) where 30% of the generation comes from intermittent renewables, 21% from hydropower (the actual contribution of hydro to the PG&E system), and the rest of the electricity is provided by the best new fossil fuel generating technology on the market today is about 5.5 cents/kWh, compared to 5.1 cents/kWh for the case (bar 3) with no intermittent renewables, 21% hydropower, and the best new fossil fuel technology. Above about 30% penetration, costs rise more quickly (e.g., compare bars 9 and 10), but such penalties can be dealt with by adding storage capacity, as will be illustrated below with an example.

When intermittent renewables are added to the system, there is a shift to less baseload and more load-following capacity on the system. A good complement to intermittent capacity on the system is generating technology characterized by low unit capital cost (because with intermittent renewables on the system the complementary technology will tend to be operated at lower capacity factor) and fast response times (to adjust to rapid changes in the output of the intermittent power generating equipment). The reduced importance of baseload generation is illustrated by a comparison of bars 2 and 7, which show that coal's share of electricity generated drops from 65% to half that level when the intermittent contribution increases from 0 to 30%.

In regions having adequate land areas for energy crops, whatever baseload power is needed could be provided by biomass power generation [12]. With 30% intermittent renewables, 21% hydropower, and biomass for baseload power (bar 9), the electricity cost should be about the same as the case involving 21% hydropower with the best new fossil fuel technology (bar 3), while the CO_2 emissions would 95% less.

Do these findings imply that the conventional wisdom about the potential roles for intermittent renewables on utility systems is incorrect? Not exactly. The calculations performed with SUTIL indicate the least-costly mix of thermal capacity and generation needed to back up a given level of penetration of intermittent renewables. For utilities with large amounts of capital-intensive baseload capacity already on the system, it would not be possible to have such large penetrations of intermittent renewables. Thus, nuclear and intermittent renewable power sources represent competitive rather than complementary strategies at large grid penetration levels. On the other hand, the ongoing shift to gas turbines and combined cycles in new generating equipment purchases is consistent with subsequent additions of intermittent renewables to the system.

3. <u>Roles For Renewable Energy Will Be Sharply Limited By The Fact That The Best Renewable Energy Resources Are Often Remote From Energy Demand Centers</u>

The best insolation is in areas like the southwest U.S. or the Sahara, where few people live. Similarly, over 90% of the U.S. wind energy resource is in the Great Plains, where the wind energy potential is 7400 TWh per year [21]—some 2.6 times total U.S. electricity generation but 13 times total generation in these states, which are thinly populated.[13] And in Asia, where booming developing economies are rapidly driving up the demand for energy, population densities are so high that large-scale biomass production for energy will likely be constrained by limited land resources.

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12 Northern California can be considered as a representative area in a global context, since the wind- and solar-energy resources are close to world averages and the use of hydroelectric power approximates the world average of 20%. The region has already successfully integrated renewables into the utility grid, and good data have been collected on the actual field performance of large operational systems. Correlations between sunlight, wind, and utility loads do not appear to be unusual.

13 For sites in the 12 Great Plains states where the mean wind power density at 50 m is greater than 400 W/m^2 (excluding 100% of environmentally sensitive and urban lands, 50% of forested lands, 30% of agricultural lands, and 10% of range lands), for turbine spacings of 5D x 10D (D = turbine rotor diameter), assuming 25%wind farm array losses.

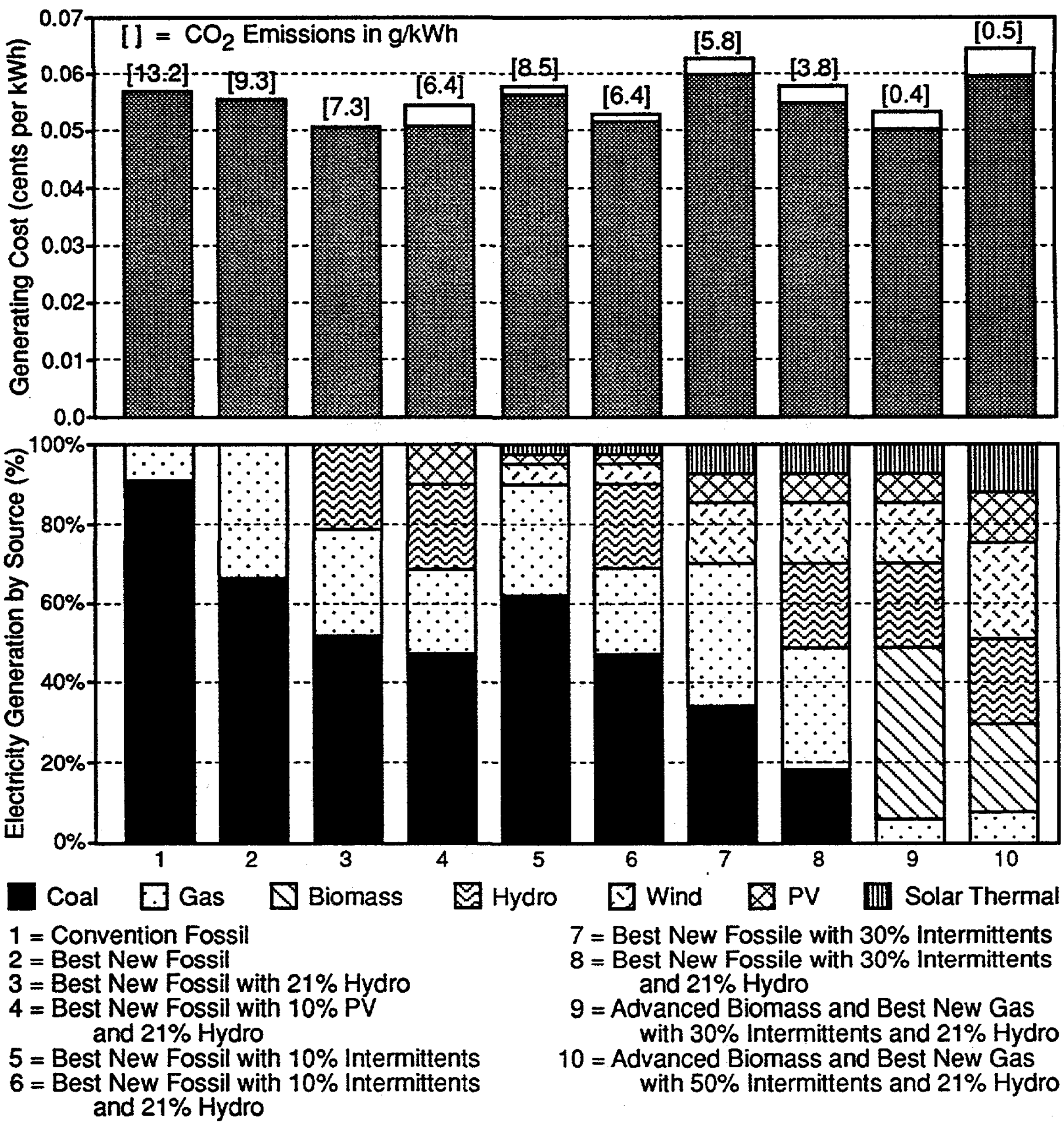

Figure 4.10: Comparing Electric Utility Investment Portfolios.

The average cost of meeting the annual electricity needs of a large utility in northern California (top) and the fraction of electricity generated by each energy source (bottom) are displayed for alternative configurations of the utility for plant operations commencing in the year 2010. The clear segments at the tops of the six bars on the right represent the value of distributed photovoltaic power to the utility system. The net cost is given by the level at the tops of the shaded bars—the gross cost less the distributed photovoltaic benefit. The figures in brackets on top of the bars (top) indicate the amount of CO_2 released into the atmosphere (in gr C/kWh) for the average mix of power plants.

The cost calculations were performed using the SUTIL (Sustainable UTILity) model developed in [20]. The costs are the result of an hour-by-hour simulation of the utility that considered electricity demand, the variable output of intermittent renewable equipment, the load-leveling capabilities of hydroelectric facilities, and the dispatching of coal, natural gas, Caption for Figure 10, cont.

and biomass-fueled electric-generating plants. The selection of coal, biomass, and natural gas-burning plants was done to minimize the cost of serving loads not covered by other equipment within the constraints specified. In this construction, "best new fossil" fuel power generating technology involves the use of the GE Frame 7F gas turbine for peaking (simple cycle fired by natural gas), load-following (gas turbine/steam turbine combined cycle fired by natural gas), and baseload (coal-integrated gasifier/combined cycle) plants. Thirty-year life-cycle coal, natural gas, and biomass prices for plants going into service in 2010 are assumed to be $2.1/GJ, $4.5/GJ, and $2.4/GJ respectively. Capital and O&M cost assumptions and assumptions about performance characteristics of alternative generating technologies are presented in [5,20], and cost accounting rules are those recommended in [3].

Do such skewed renewable resource distributions pose serious constraints on the development of renewable energy? Actually, the distribution of renewable resources is not so skewed as many think. In the U.S. annual average global insolation (direct plus diffuse) varies by only 1.5 to 1. And most regions are well endowed with one or more renewable resources. (For example, substantial quantities of hydrogen could be produced from local renewable sources in most U.S. states [25]). Nevertheless, it is true that some regions are better endowed than others. As a result, in a world where renewable energy is developed on a large scale, it is likely that there would often be large interregional energy flows—both within countries and among countries [5].

In some ways the imbalance between resources and energy demand will be advantageous. One important lesson that has come out of the development of wind power in the Altamont Pass in California is that the NIMBY[14] problem that has plagued so many conventional energy projects has not been a serious problem there. The reason seems to be related to the fact that this is primarily a ranching area. The infrastructure needed for wind farms takes up less than 5% of the land area, so that ranching can continue on wind farms. Moreover, ranchers receive large royalty rents from wind producers that have sharply driven up land values in the Altamont. Ranchers and wind producers seem to have developed relatively comfortable working relationships. The fact that ranching and farming are the major industries in the Great Plains suggests that the good NIMBY experience at Altamont might be transferable to this region as well. (In Europe, where the areas with good wind resources tend to have much higher population densities, wind power seems to have more of a NIMBY problem.)

To tap a substantial fraction of the total wind energy potential in the Great Plains will require finding ways to deliver wind energy to major demand centers outside the Great Plains. A good way to transport wind electricity at relatively low cost to remote markets is via dc transmission lines for baseload electricity provided by a system consisting of wind turbines plus underground compressed air energy storage (CAES) [22]. There is suitable geology for CAES in many parts of the Great Plains. The prospective economics of such a system that would go into operation in 2010, involving a wind farm in Kansas (where the wind resource is very good) that delivers "baseload wind power" to California, where it provides 40% of total electricity, is illustrated in Figure 4.11. With current fossil fuel-based generating technology, the cost of electricity with wind would be less than without, and CO_2 emissions would be reduced nearly in half. If instead the current fossil fuel system were to be entirely replaced by the best fossil fuel technology now on the market, the cost of electricity with wind would be more than without, but CO_2 emissions would be 60% less than for the current fossil fuel system without wind power on the system. If a carbon tax of $90/tC were assessed on utility fossil fuel purchases, however, the costs would be the same, with and without wind, and slightly less than for the current fossil fuel system without wind (see Figure 4.11).

Much further in the future it might also make sense to produce hydrogen electrolytically from photovoltaic sources in areas of intense insolation, such as North Africa, and pipe it to Europe for use in transport markets via fuel cells [25]. Natural gas is already transported to

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[14] NIMBY = not in my backyard.

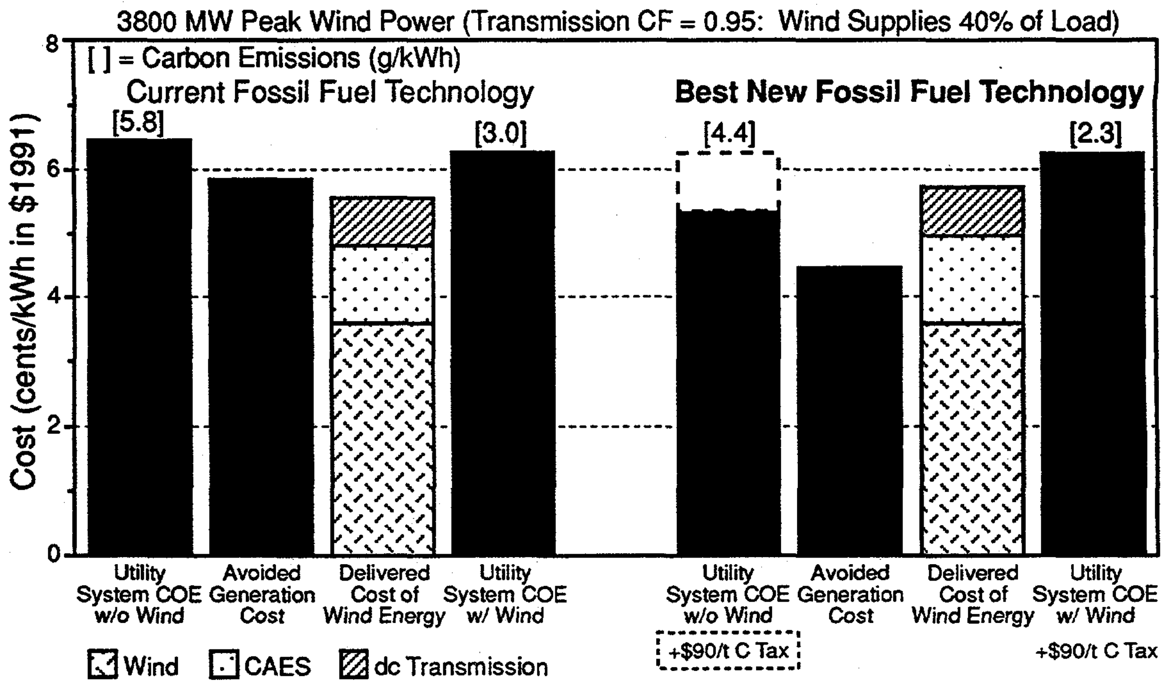

Figure 4.11: Electric Power Generation Costs In California With And Without Wind Power From Kansas (*circa* 2010).

Here two direct current (dc) transmission line carry baseload electricity to California from a system in Kansas consisting of a large wind farm plus compressed air energy storage (CAES). This system provides 40% of the total electricity load in California. It is assumed that the system goes into operation in 2010. (The fossil fuel price assumptions are the same as in Figure 4.10. For details see [22].)

The four bars on the left indicate costs for the case where the fossil fuel power generating technology complementing this baseload wind power is characterized by present average heat rates for power plants in California. The bar on the far left is the average cost of electricity with no wind on the system; the second bar is the cost of electricity avoided by not having to produce electricity from fossil fuel with wind power on the system; the third bar is the cost of wind electricity delivered to California, desegregated by component: generation cost, compressed air energy storage cost, and dc transmission cost; the fourth bar is the average cost of electricity with wind power on the system. The four bars on the right are for the case where the fossil fuel generating technology is based on the use of the General Electric Frame 7F gas turbine, as in Figure 4.10; system electricity costs include a carbon tax ($90/tC) large enough to make the average cost of electricity the same, with and without the wind power. The numbers on the tops of the electricity generating cost bars are the average CO_2 emission rates, in gr C/kWh.

Europe via pipeline under the Mediterranean. While hydrogen has only 1/3 the heating value of natural gas, transport costs (per unit of delivered energy) are only twice as large as for natural gas, because higher volumetric flow rates are possible with hydrogen, a slipperier molecule than methane. And when hydrogen is used in fuel cells, this extra cost would be offset by the higher energy conversion efficiencies for electrochemical conversion compared to combustion-based systems.

Long before electrolytic hydrogen comes into large-scale use, fuels derived from biomass could play major roles in international markets. While the energy density of fresh biomass is very low compared to coal, the biomass feedstock can be processed near where it is grown into a high-quality fuel such as methanol, which has a volumetric energy density 1/2 that for gasoline. In a renewables-intensive energy future the preferred use of this methanol would be in fuel cell vehicles. Because such vehicles would be more than twice as energy-efficient as gasoline internal-combustion-engine vehicles, transport costs per km of car travel would be about the same. Thus international commerce in biomass-derived methanol would make sense if the economics made sense and if adequate resources were available to support such commerce.

The prospects of favorable economics for biofuels in transportation are auspicious for the U.S., if fuel cell vehicles are successfully developed (see Figures 4.9 and 4.12). The prospective economics should be even better in developing countries because labor is cheaper there (biomass production is very labor-intensive) and because growing seasons tend to be longer in most developing countries.

In *Renewable Energy*, a preliminary survey was made of world regions to ascertain where biomass might be produced for future energy markets at levels substantially in excess of local energy demand. In this survey, the most promising land use categories for such large-scale plantations were found to be those deforested and otherwise degraded lands judged to be suitable for reforestation and not likely to be needed for food production in the period to the middle of the next century. Most such lands are located in Latin America and in sub-Sahelian Africa [5,26].

In the renewables-intensive global energy scenario (RIGES) developed in [5], biomass-derived fuels (mainly from Latin America and sub-Sahelian Africa) account for 30% of international trade in fluid fuels in 2050 and electrolytic hydrogen produced in North Africa and the Middle East another 7% (see Figure 4.13). While the overall level of world trade in fluid fuels in RIGES in 2050 would be 70% higher than at present, there would be greater energy security in the world than at present, both because of the diversity of energy carriers traded (comparable shares of energy traded in the forms of oil, natural gas, and methanol from biomass) and the diversity of suppliers—with biomass methanol producers in Latin America and sub-Sahelian Africa having market power comparable to that of the Middle East oil producers. Moreover, the intense competition in energy markets would lead to a capping of the world oil price in the long term at a level of the order of $25 per barrel. Thus without substantial taxes on externalities (e.g., a carbon tax) it is probably incorrect to think that high energy prices will propel a shift to renewable energy. The prospect of relatively stable world energy prices in the long term underscores the importance of identifying renewable energy strategies that are viable at relatively low energy prices. The RIGES was developed in this spirit.

4. <u>Without The Benefit Of A Stiff Carbon Tax, Biomass Cannot Compete In Either Electric Power Or Fluid Fuels Markets, Because Biomass Feedstocks Are Inherently More Costly Than Coal, Which Is Abundant</u>

The planting, cultivation, and harvesting of biomass is generally more labor-intensive than recovering coal from the ground. For this reason it is generally believed that, per unit of contained energy, biomass is the more costly, especially where there are abundant indigenous coal resources. There are two problems with this reasoning.

First, it is not generally true in many developing countries. There low labor costs and long growing seasons often lead to relatively low costs for biomass [14], especially in areas where there are no substantial resources of coal or where coal resources are of low quality.

This characterization is generally true, however, for many industrialized countries. But even in these instances, it does not follow that biomass energy systems cannot be cost-competitive with coal-based energy systems. There are two characteristics of biomass feedstocks that make it possible for biomass to be competitive with coal, even if the biomass feedstocks are more costly:

- Biomass contains very little sulfur, the cost-effective removal of which is still a major challenge for coal, even though a great deal of research and development has been committed to the task.
- Biomass is far more reactive than coal, making it possible to gasify biomass at lower temperatures and at faster rates than is feasible with coal.

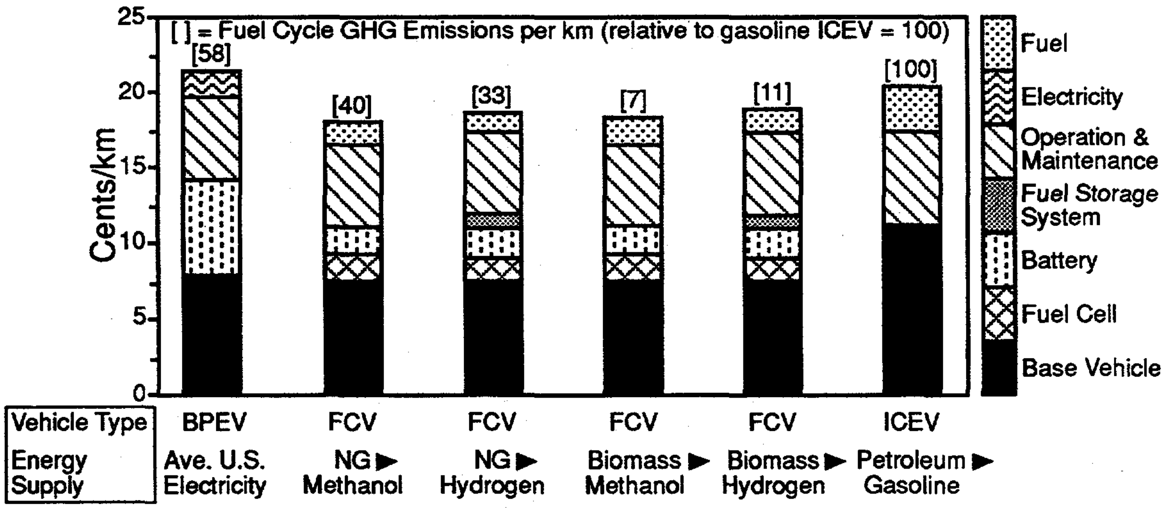

Figure 4.12: Life-Cycle Costs Of Alternative Automobile/Energy Carrier/Primary Energy Source Combinations (cents per kilometer)—Medium Term Options.

The life-cycle costs are based on the use of an automobile performance/cost model developed by Mark A. DeLuchi at the University of California at Davis. The fuel cost components of the life-cycle costs for the alternative energy carriers are presented in Figure 4.9. The numbers at the tops of the bars show the greenhouse gas emissions per kilometer of driving (relative to a gasoline ICEV = 100) over the entire fuel cycle, in carbon dioxide-equivalent terms. Here NG = natural gas. The details of the construction of this figure are presented in [19].

In the case of both coal and biomass, thermochemical gasification is the key to unlocking large potential markets. The products of gasification can be used either to generate electricity in gas-turbine based power plants (combined cycles, intercooled steam-injected gas turbines, etc.) that are more energy-efficient and that produce far less pollution than steam-electric power-generating technologies [12,13], or to produce transport fuels (e.g., methanol or hydrogen) [27].

For either application, coal is gasified in oxygen, both because oxygen is needed to generate the very high temperatures needed to get coal to react at a sufficiently high rate and because oxygen-blown gasifiers facilitate sulfur removal. The problem with oxygen-blown gasifiers is that oxygen production is capital intensive and the costs are very scale-sensitive. As a result coal gasification plants tend to be very large, entailing substantial front-end costs.

Oxygen is not needed to gasify biomass. As a result, biomass plants can be built at much smaller scales than is cost-effective for coal, close to where the biomass is grown, to reduce fuel transport costs. For power generation, biomass can be gasified in air at lower capital costs because neither an oxygen plant nor sulfur removal equipment is needed. High efficiencies and low unit capital costs can be realized at very modest scales (100 MW_e or less) for the turbomachinery as well by using gas turbines derived from aircraft engines—so-called aeroderivative gas turbines [12,13].

For the production of methanol or hydrogen from biomass, air gasification is not appropriate, because it would be necessary to remove the nitrogen diluent from the gasification products—a costly task. However, it is feasible to gasify biomass in a steam environment that gives rise to a largely nitrogen-free product gas that can easily be transformed into methanol or hydrogen using commercial technology. Steam gasification reactions are driven by heat from an external combustor and the overall process is referred to as "indirect gasification." The low reactivity of coal makes it impractical to gasify coal this way; rather, some coal is partially combusted in oxygen in the gasifier to generate much high temperatures than what can be achieved with indirect gasification.

INTERREGIONAL FLUID FUEL EXPORTS IN RENEWABLES-INTENSIVE GLOBAL ENERGY SCENARIO
(millions of barrels of oil-equivalent per day)

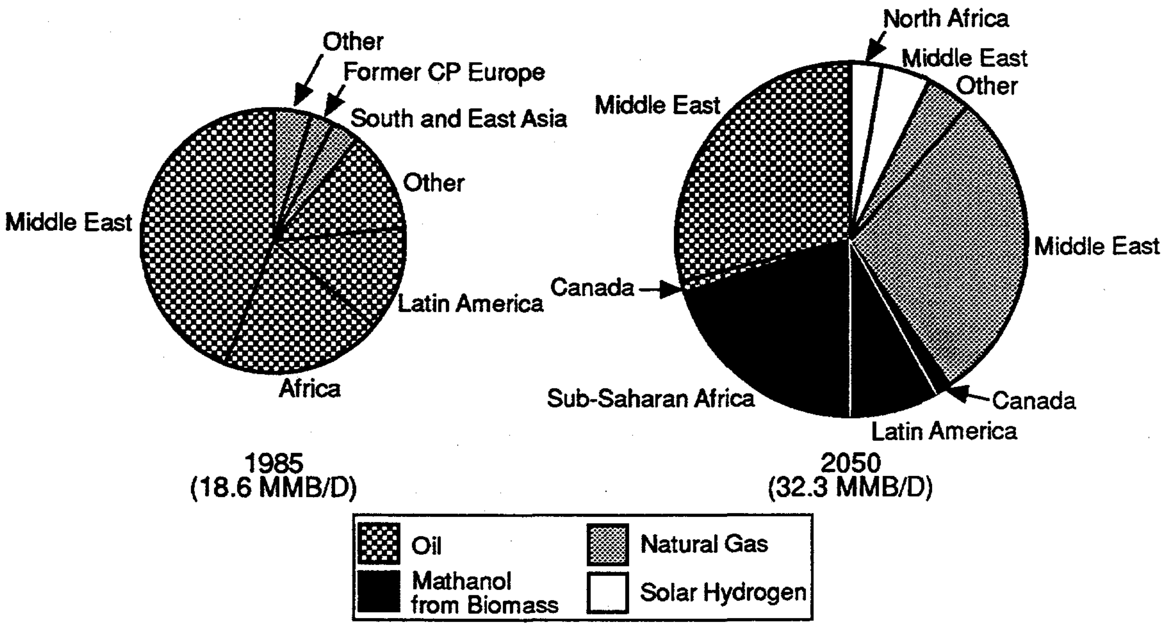

Figure 4.13: Interregional Fuels Flows For The Renewables-Intensive Global Energy Scenario.

The importance of world energy commerce for the renewables-intensive global energy scenario developed in [5] and for which global primary energy consumption is shown in Figure 4 is illustrated here. The figure shows that by the middle of the next century there would be comparable interregional flows of oil, natural gas, and biomass-derived methanol, as well as small flows of hydrogen derived from renewable sources. This diversified supply mix is in sharp contrast to the situation today, where oil dominates international commerce in liquid and gaseous fuels.

Most methanol exports would originate in sub-Saharan Africa and in Latin America, where there are vast degraded areas suitable for revegetation that will not be needed for cropland [5]. Growing biomass on such lands as feedstocks for producing methanol (or other biomass fuels) would provide a powerful economic driver for restoring these lands.

Because of such advantages in gasification, the prospects are good that BIG/GT power plants at scales of 100 MW_e or less would be competitive with coal-integrated gasifier/combined cycle power plants that are much larger [12,13], and that methanol or hydrogen production from biomass would be competitive with the production of these fuels from coal at much larger scales (see Figure 4.9), even if the biomass feedstock is the more costly [27].

5. Because Its Production Is So Land-Intensive, Biomass Can Make Only Marginal Contributions To Overall Energy Requirements

Many will be very skeptical about the major role envisaged for biomass energy in the renewables-intensive global energy scenario, because the low efficiency of photosynthesis implies large land areas for energy crop production. For example, displacing fossil fuels in the U.S. with the energy equivalent amount of biomass grown on plantations at the average productivity of U.S. forests (4 dry tonnes per hectare per year) would require a plantation area of 1 billion hectares—approximately the total U.S. land area. This "back-of-the-envelope" calculation suggests that biomass can never become a significant energy source. While it is certainly true that biomass resources are not large enough to enable biomass to provide all energy needs, the role of biomass nevertheless can be substantial, if modern technologies are used for biomass production and conversion.

The land constraints on biomass production can be reduced in part by intensively managing the biomass plantations. With modern production techniques, biomass productivities far in excess of natural forest yields can be realized. A reasonable goal for the average harvestable yield on large-scale plantations in the U.S. is 15 dry tonnes per hectare per year [26]—corresponding to a photosynthetic efficiency of about 0.5%. The amount of land that might be committed to biomass energy plantations in the U.S. could be over 50 million hectares—the amount of excess cropland projected by the U.S. Department of Agriculture to be available by the year 2030 [28]. However, for the purposes of the present discussion, it is assumed that by that time the amount of land in the U.S. committed to biomass plantations is a more modest 30 million hectares—approximately the amount of excess cropland in the U.S. at present. Potential biomass production on this much land at 15 tonnes per hectare per year would amount to about 9 EJ per year.

The land constraints on biomass production can also be eased by exploiting for energy purposes biomass residues (urban wastes and residues of the agricultural and forest-product industries) that can be recovered in environmentally acceptable ways. It has been estimated that such residues in the U.S. could amount to about 6 EJ per year [29].

The biomass energy potentially available from these two sources, some 15 EJ per year, could probably be produced in the U.S. in environmentally acceptable ways without running up against significant land-use constraints. The extent to which conventional energy could be displaced with this much biomass depends sensitively on the conversion technologies deployed.

Consider, for example, the two energy activities often targeted for replacement by biomass energy—the generation of electricity from coal and the running of light-duty vehicles (automobiles and light trucks) on gasoline. In the U.S. these activities in 1987 accounted for some 30 EJ of primary energy and about half of total CO_2 emissions from fossil fuel burning. If these two activities (at 1987 activity levels) could be replaced by biomass grown renewably, the result would be a 50% reduction in U.S. CO_2 emissions.

Suppose first that biomass were used with commercially available technologies: (i) replacing coal-based steam-electric power plants with biomass-based steam-electric power plants having a 20% average efficiency and (ii) replacing gasoline-fired internal-combustion-engine light-duty vehicles having 1987 average fuel economies, with the internal-combustion-engine vehicles operated on methanol derived from biomass (using commercially available technology designed to make methanol from coal but modified to accommodate biomass), assuming no improvement in the fuel economy of the vehicles other than what would be inherent in a shift from gasoline to methanol (gasoline-equivalent fuel economies of 23 mpg for autos and 16 mpg for light trucks). The amount of biomass needed for this conversion would be about 49 EJ per year (see Figure 4.14)—far more biomass than is likely to be available for energy purposes.

By the turn of the century, the first generation of biomass-integrated gasifier/gas turbine technology will probably be commercially available, making it possible to roughly double the efficiency of biomass power generation [12]. In this time frame more energy-efficient biomass-to-methanol conversion technologies may well be available [27]. Moreover, it is feasible and cost-effective to introduce light-duty vehicles operated on methanol having much higher fuel economies (gasoline-equivalent fuel economies of 39 mpg for autos and 26 mpg for light trucks). Using these technologies the total biomass required to displace all coal power generation and oil use by light-duty vehicles at 1987 activity levels would be reduced to 23.5 EJ per year (see Figure 4.14).

During the second decade of next century, even more energy-efficient fuel cell technologies are likely to be available, both for power generation (57% efficient biomass-integrated gasifier/fuel cell systems employing molten-carbonate or solid-oxide fuel cells) and for motor

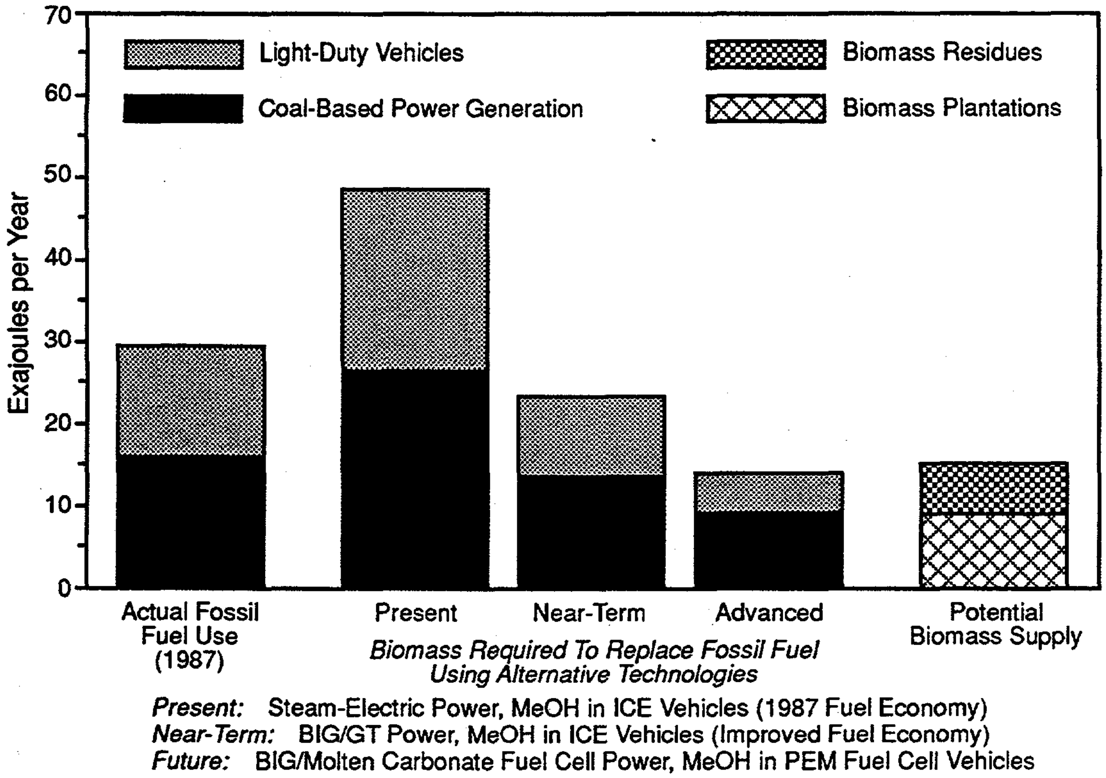

Figure 4.14: Energy For Light-Duty Vehicles And Power Generation In The U.S.

Shown here are the biomass primary energy requirements for displacing all petroleum used by light-duty vehicles (automobiles and light trucks) and all coal-fired power generation in the US, at the 1987 activity levels, with alternative biomass technologies, in relation to potential biomass supplies. (See [23] for the details of the construction of this figure.)

The bar on the left shows fuel actually consumed in 1987 by light-duty vehicles and by coal-fired power plants. The second bar shows the biomass primary energy requirements if light-duty vehicles and coal-fired power plants at 1987 activity levels were replaced by biomass energy systems that are commercially available today. The third bar shows biomass requirements if technologies likely to be available in the year 2000+ time frame were used to replace all oil used for light-duty vehicles and all coal-based power generation, at 1987 activity levels. The fourth bar shows the biomass requirements if technologies likely to be widely available in the 2020 time frame were used to replace all oil used for light-duty vehicles and all coal-based power generation, at 1987 activity levels. The bar on the right shows potential biomass supplies from plantations on 30 million hectares of excess agricultural lands plus residues (urban refuse plus agricultural and forest product industry residues) that are recoverable under environmental constraints.

vehicle applications (proton-exchange-membrane fuel cell vehicles that are 2.5 times as energy-efficient as comparable gasoline-fired internal-combustion-engine vehicles). Using these technologies the total biomass required to displace all coal power generation and oil use by light-duty vehicles at 1987 activity levels would be reduced to about 14 EJ per year, which is comparable to the above estimate of potential supplies from plantations and residues (see Figure 4.14).

Thus with advanced technologies biomass can play major roles in the energy economy, despite the low efficiency of photosynthesis.

6. Biomass Energy Poses Serious Environmental Problems

To many people the growing of biomass for energy on a large scale is viewed as a massive assault on nature. It seems to be contrary to the widely held view that we should be finding ways to preserve more of our natural forests instead of finding new uses for biomass. And intensive agricultural management practices, which would also characterize biomass energy plantations, are increasingly under attack by environmentalists concerned about the resulting chemical contamination of groundwater and loss of soil quality. Unless such concerns can be effectively dealt with, so as to gain wide public support for biomass energy production, it will be difficult to achieve the major role for biomass envisaged for the RIGES.

There is no doubt that biomass can be grown for energy in ways that are environmentally undesirable. However, it is also possible to improve the land environmentally through the production of biomass for energy. The environmental outcome depends sensitively on how the biomass is produced.

Consider first the challenge of sustaining the productivity of the land. Since the harvesting of biomass removes nutrients from the site, care must be taken to ensure that these nutrients are restored. In various ways this challenge can be dealt with for energy plantations more easily than is feasible in agriculture or in industrial fiber production, largely as a result of the fact that energy markets allow flexibility in the choice of biomass feedstocks, so that choices can be made to better meet environmental objectives. This is especially true for biomass conversion technologies that begin with thermochemical gasification (which will often be the preferred approach for providing modern energy carriers from biomass feedstocks); such processes can accommodate a wide range of alternative feedstocks.

With thermochemical gasification it is feasible to recover all mineral nutrients as ash from the gasifier at the biomass conversion facility and to return the ash to the plantation site for use as fertilizer. Of course, fixed nitrogen lost to the atmosphere at the conversion facility must be replenished. However, there are several ways this can be accomplished in environmentally acceptable ways. First, when trees are the harvested crop, the leaves, twigs, and small branches, in which nutrients are concentrated, can be left at the site to reduce nutrient loss. (So doing also helps maintain soil quality and reduce erosion through the addition of organic matter to the soil.) Also, nitrogen-fixing species can be selected for the plantation or for interplanting with the primary plantation species to eliminate or reduce to low levels the need for artificial fertilizer inputs. The promise of intercropping strategies is suggested by 10-year trials in Hawaii, where yields of 25 dry tonnes per hectare per year were achieved without nitrogen fertilizer when Eucalyptus was interplanted with nitrogen-fixing Albizia trees [30]. Biomass production for energy allows much more flexibility than is possible with agriculture in meeting fixed nitrogen requirements this way. In agriculture, the market dictates the choice of feedstocks with a narrow range of acceptable characteristics, but the conversion technology usually puts few restrictions on the choice of biomass feedstock for energy systems, aside from the requirement of high productivity, which is needed to keep costs at acceptable levels.

Energy crops also offer flexibility in dealing with erosion and with chemical pollution from herbicide use. These problems occur mainly at the time of crop establishment. Accordingly, if the energy crop is an annual crop (e.g., sweet sorghum), the erosion and herbicide pollution problems would be similar to those for annual row-crop agriculture. The cultivation of such crops should be avoided on erodible lands. However, the choices for biomass energy crops also include fast-growing trees that are harvested only every 5 to 8 years and replanted perhaps every 15 to 24 years and perennial grasses that are harvested annually but replanted perhaps only once in a decade. In both cases erosion would be sharply reduced, on average, as would the need for herbicides.

Another concern is chemical pollution from the use of pesticides to control the plantation crop against attack by pests and pathogens. While plantations in the tropics and subtropics tend to be more affected by disease and pest epidemics than those in temperate regions, experience with plantations in these regions shows that careful selection of species and good plantation design and management can be helpful in controlling pests and diseases, rendering the use of chemical pesticides unnecessary in all but extraordinary circumstances. A good plantation design, for example, will include: (*i*) areas set aside for native flora and fauna to harbor natural predators for plantation pest control, and perhaps (*ii*) blocks of crops characterized by different clones and/or species. If a pest attack breaks out on one block, a now common practice in well-managed plantations is to let the attack run its course and to let predators from the set-aside areas help halt the pest outbreak [26].

Biomass plantations are often criticized because the range of biological species they support is much narrower than for natural forests. While this is generally true, the criticism is not always relevant. It would be relevant if a virgin forest were replaced with a biomass plantation. However, it would not be relevant if a plantation and associated natural reserves were established on degraded lands; in this instance, the restored lands would be able to support a much more diverse ecology than was possible before restoration. If biomass energy crops were to replace monocultural food crops, the effect on the local ecology would depend on the plantation crop species chosen, but in many cases the shift would be to a less ecologically simplified landscape [29].

As already noted, establishing and maintaining natural reserves at plantations can be helpful in controlling crop pests while providing local ecological benefits. However, preserving biodiversity on a regional basis will require land-use planning in which natural forest patches are connected via a network of undisturbed corridors (riparian buffer zones, shelterbelts, and hedgerows between fields), thus enabling species to migrate from one habitat to another [29].

While major expansions in research are needed to provide a sound analytical and empirical basis for achieving and sustaining high biomass yields in environmentally acceptable ways, there is time for this research and extensive field trials, because major bioenergy industries can be launched using as feedstocks primarily residues from the agricultural and forest products industries. If substantial commitments are made to biomass plantation research in the near term, plantation biomass could start to make contributions to energy when residue supplies are no longer adequate to meet the needs of the growing biomass energy industry, near the turn of the century or shortly thereafter.

7. To Achieve Deep Reductions In Greenhouse Gas Emissions In A Greenhouse-Constrained World, Both Nuclear And Renewable Energy Sources Will Be Needed On Large Scales

Concerns about greenhouse warming could lead to calls to reduce greenhouse gas emissions to levels far below the levels characterizing the RIGES, for which emissions in 2050 are about 1/4 less than in 1985 (see Figure 4.4). To prevent any further climate change beyond that inevitable because of past greenhouse gas emissions would require cutting emissions by 60% or more, according to the Intergovernmental Panel on Climate Change [31]. Would this not require large-scale commitments to both nuclear and renewable energy?

To address this question, consider the RIGES more closely. Even though global electricity generation grows at an average rate of 1.9% per year, 1985-2050 (see Figure 4.5), compared to 0.6% per year for total primary energy (see Figure 4.4), electricity's contribution to CO_2 emissions in 2050 is the same as in 1985—about 1/4 of the total (see Figure 4.15). Thus in conventional electricity markets nuclear electricity could not do much more in reducing CO_2 emissions than what the RIGES indicates can be accomplished with renewables. To the extent that nuclear would play a substantial role in reducing emissions in conventional electricity markets it would be instead of renewables rather than as a complement to renewables.[15] Thus in seeking to identify opportunities for nuclear power to reduce emissions substantially one should look to markets where fuels would otherwise be used directly.

For fuels used directly, transportation is the fastest growing sub-market, and the automobile represents the most difficult market to serve with alternatives to the petroleum-

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[15] In conventional baseload electricity markets nuclear would compete for market share with biomass and with intermittent renewables coupled to appropriate electrical storage capacity. Moreover, as pointed out earlier, even without storage, high penetrations of intermittent renewables would lead to reduced requirements for baseload power.

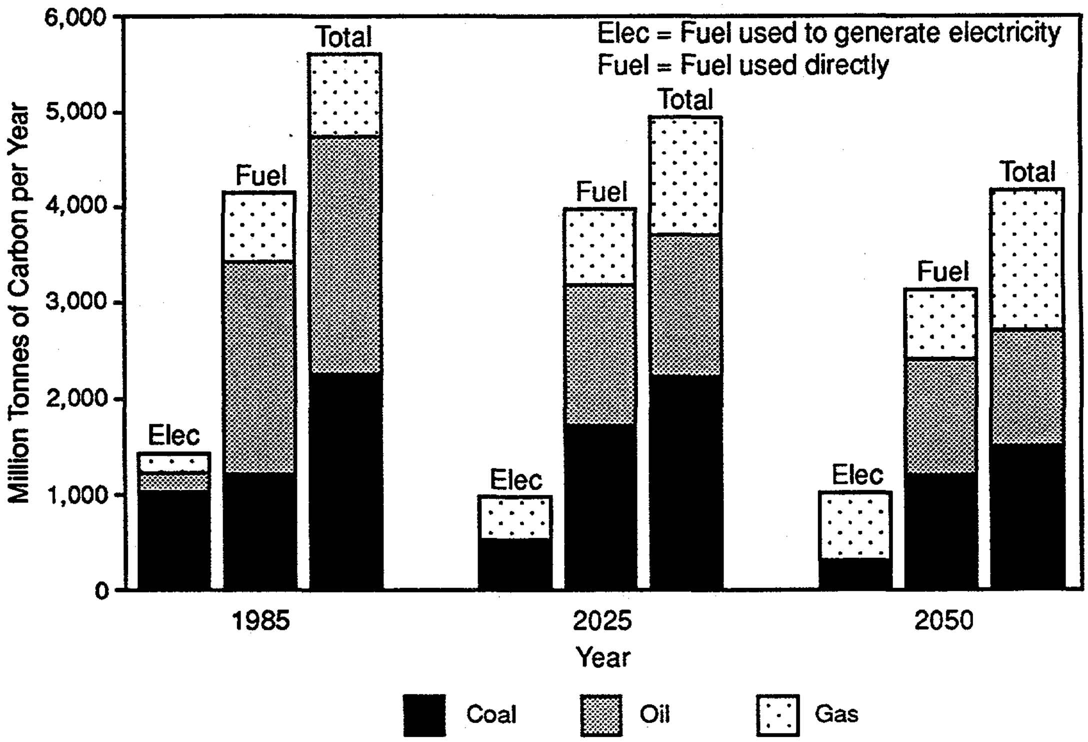

Figure 4.15: Emissions Of CO_2 For The Renewables-Intensive Global Energy Scenario, By Energy Carrier.

Despite the expected growing share of energy going to power generation, the power sector's share of global CO_2 emissions would not increase in the period 1985-2050 from the present relatively low level (about 1/4 of total emissions), in a renewables-intensive global energy future. Accordingly, if society should choose to reduce emissions further than is indicated for the global energy scenario developed in [5], only modest further reductions could be achieved by substituting additional carbon-free power-generating sources for fossil fuel power-generating sources. Much greater reductions could be achieved by substituting renewable fuels for fossil fuels used directly. The least costly renewable fuel options for such substitutions would be biomass fuels (e.g., methanol and hydrogen). More land could be committed to biomass production than was assumed for the scenario illustrated here—especially in Africa and Latin America. In addition, vast quantities of hydrogen could be produced from wind and photovoltaic sources without encountering land or water availability constraints.

based internal combustion engine.[16] Thus understanding the prospects for displacing the gasoline-powered internal-combustion-engine car is key to getting a handle on the prospects for reducing CO_2 emissions from activities in which fuels are used directly.

Suppose it is decided to use nuclear power in the automotive transport market. This could be done in various ways, but the major options are likely to be: (i) the battery-powered electric vehicle (BPEV); or (ii) the fuel cell vehicle (FCV) operated on electrolytic hydrogen. Detailed cost estimates for both vehicles under mass production conditions [19] indicate that both the first cost of the vehicle and the life-cycle cost of owning and operating the car (in cents/km) would probably be less for the FCV option (see Figure 4.16) [19] . And of course, FCVs could be refueled in minutes, while it takes hours to recharge BPEVs.

16 Capital-intensive alternative propulsion systems such as batteries and fuel cells will fare better in buses, trucks, and trains, which have duty factors of 50% or more, than in cars, for whiich the duty factor is 5% or less. Also, buses, trucks, and trains can better accommodate energy carriers having low energy density (e.g. hydrogen) because more space can be made available for fuel storage.

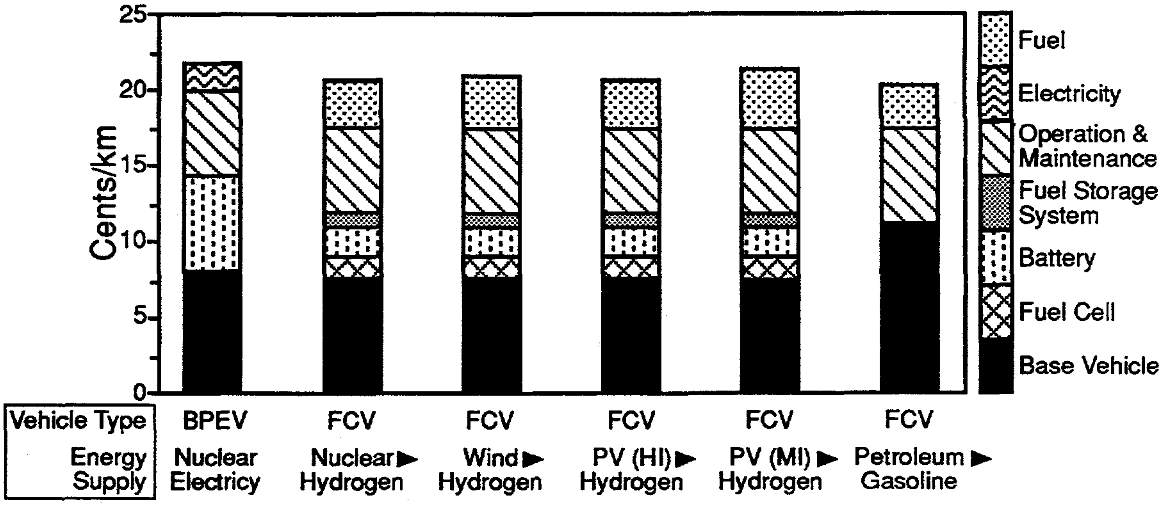

Figure 4.16: Life-Cycle Costs Of Alternative Automobile/Energy Carrier/Primary Energy Source Combinations (cents per kilometer)—Long-Term Options.

The details of the construction of this figure are presented in [19]. The life-cycle costs are based on the use of an automobile performance/cost model developed by Mark A. DeLuchi at the University of California at Davis. For all the options other than the gasoline ICEV, the direct greenhouse gas emissions are zero. A long-term perspective is taken here, and it is assumed that zero net greenhouse gas-emitting energy sources are used to provide indirect energy inputs throughout the fuel cycle as well, so that total life-cycle greenhouse emissions for all these options are zero.

Here PV = photovoltaic electricity; HI = in an area of high insolation (2400 kWh per m^2 per year), typical of the Southwest of the U.S.; MI = in an area of moderate insolation (1800 kWh per m^2 per year), the average insolation in the U.S.

Hydrogen produced electrolytically from wind or thin-film photovoltaic power sources (*circa* 2010) would probably have a cost comparable to that for nuclear hydrogen (see Figure 4.9) and life-cycle costs would be even closer in value than fuel costs (see Figure 4.16). Moreover, electrolytic hydrogen could be produced from renewable sources in very large quantities without running up against resource constraints. For example, photovoltaic hydrogen adequate to support the entire U.S. light-duty vehicle fleet at the level of driving projected by the Department of Energy for 2010 (4.3 trillion vehicle kilometers) could be produced on a land area equal to 0.1% of total U.S. land area. Alternatively, about 270 GW_e of nuclear capacity would be needed. The choice between nuclear and renewable electrolytic options will be determined on the basis of considerations other than direct costs; society should decide on the basis of comparative externalities which option is preferable.

If it were decided that society should shift from gasoline ICEVs to hydrogen FCVs, electrolytic hydrogen would be adopted only when further increases in supplies of much less costly hydrogen sources are not possible.

Natural gas is by far the least-costly source of hydrogen. Hydrogen can be produced from natural gas priced at $3 per GJ in a thermally-integrated plant at a cost of $5 per GJ and a cost to consumers of $11 per GJ at a HHV efficiency of 85% (see Figure 4.9) [19,27]. If this hydrogen were used in FCVs to support the entire US light-duty vehicle fleet at the level of driving projected for 2010, the natural gas required would be 5.7 EJ—about 2/5 of the petroleum accounted for by LDVs in 1990, when the amount of driving was just 2/3 as much as is projected for 2010. Life-cycle greenhouse gas emissions for the natural gas/hydrogen FCV option would be just 1/3 of those from the gasoline ICEV displaced.

Biomass will be the least costly source of hydrogen from renewable sources. For plantation biomass costing $2.5 per GJ, hydrogen could be produced at a cost of $8 per GJ or $14 per GJ delivered to the consumer (see Figure 4.9) [19,27]. Hydrogen from biomass could support the year 2010 level of driving for the light-duty vehicle fleet with 7.1 EJ of biomass grown on 23 million hectares of plantations (assuming a productivity of 15 tonnes per hectare per year). The base-case projection of the Department of Agriculture is that by 2030 the U.S. will have 57 million hectares of excess cropland [28]. The key question here is not whether there will be enough land for biomass to play a major role in transportation but rather whether this much biomass can be grown on plantations in environmentally acceptable ways. One can "buy" an enormous amount of environmental protection and still leave biomass hydrogen far cheaper than electrolytic hydrogen.

In the long run, as natural gas supplies get tight and land-use constraints prohibit further expansion of biomass production for energy, mankind will turn to electrolytic hydrogen. Does nuclear have a role? It is difficult to make a convincing case that electrolytic hydrogen derived from nuclear power will be cheaper than electrolytic hydrogen derived from renewable electric sources, or that both nuclear power and renewables will be needed. Rather it must be argued on the basis of considerations of externalities that nuclear power is preferable to or at least it is no less preferable than renewable energy.

CONCLUSION

Enormous progress has been made on many fronts relating to renewable energy over the past decade. With adequate public sector support for both research and development and for market stimulation, there are good prospects that over the next decade or so we could see a range of renewable energy options entering mass energy markets. The fact that renewable energy equipment is small and modular suggests that the level of support needed for a diversified portfolio of new renewable technologies is likely to be modest in relation to historical public sector levels of support for advancing fossil fuel and nuclear energy technologies.

Nuclear and renewable energy strategies should be viewed largely as competitive rather than as complementary. The choice between these alternatives should be based largely on the basis of considerations of externalities, as a good case cannot be made that nuclear power will be cheaper or that both nuclear and renewable energy technologies will be needed.

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RESPONSE TO R.H. WILLIAMS

WHAT NOW?
An Examination of the Impact of the Issues Raised

Lawrence M. Lidsky and Steven M. Cohn

INTRODUCTION

Nuclear power research and development has been based on the premise that nuclear power would play a dominant role in the world's energy economy and that it would assume that role in a relatively short time. As Professor Williams' paper demonstrates, the assumption of nuclear power dominance is not self-evident. Insofar as time scale is concerned, it has become clear that the growth rate of nuclear power will be quite modest for the next several decades. Clearly, both the level and the focus of nuclear power research and development will change.

We analyze the impact of "successful development" of renewable energy technologies (RETs) on nuclear power research and development. We define successful development as acceptance by planners of the *idea* that RETs and fossil fuels can meet expected incremental electricity demand in the U.S. at ~6 c/kWh or less over the next 10-20 years and an optimism (though not certainty) about the ability of RETs, increased energy efficiency, and improved fossil burning technology to meet long-run (40-year planning horizon) electricity demand without significant electricity cost increases or environmental degradation. We have limited our discussion to the U.S. economy, but suspect that global issues would not alter our conclusions with respect to U.S. energy policy.

The immediate impact of the *belief* that RETs and fossil fuels can meet demand will be to reduce the already low probability that nuclear plants will be ordered during the next 10-20 years. This is not a major change. The biggest impact will be on nuclear power R&D. Nuclear energy has heretofore enjoyed generous and assured government R&D support due to the assumption of a nuclear imperative. Once the availability of non-nuclear energy alternatives is accepted, nuclear energy must compete with these options for R&D dollars. Although a few planners may retain the notion of a very long run nuclear imperative, pushing the time frame for a possible nuclear renaissance very far into the future minimizes its impact on current R&D choices. With short-term deployment and long-term inevitability absent, there will be stringent limits on federal nuclear R&D spending. We discuss below the possible justifications for any funding level greater than zero as well as the potential benefit of a "nuclear interregnum."

SUPPORTABLE FUNDING LEVEL

It is impossible (and unnecessary for our purposes) to predict the exact funding profile of the various energy technologies. But the "natural"funding level for nuclear power R&D can be estimated within a factor of two or so. Recent studies indicate that there are very many attractive non-nuclear energy supply and energy efficiency R&D options (ORNL 1989, Alliance, et al., 1991, Johansson, et al., 1993). Opportunity cost comparisons are thus likely to limit **maximum** government fission R&D funding to levels comparable to that granted to the substantial number of competing technologies. The question of minimum level is more difficult to resolve and it will increasingly devolve upon nuclear power's proponents to argue for a non-zero level.

The DOE's recent energy supply and R&D budget categories aggregate to $4 to $4.5 billion/yr. and are unlikely to grow significantly in the foreseeable future [U.S. DOE-EIA 11/92, p. 43, Federal Energy R&D Appropriations minus general science funding FY91-FY93]. About half the budget is allocated to basic energy research, environmental restoration, common facilities and overhead, and half earmarked for specific technologies, such as fusion and fission power, fossil fuels, RETs, and energy conservation. Given the array of promising technologies in all of these fields, fission power is unlikely to receive more than 10% of earmarked funds, with some of this allotment targeted for technological maintenance (e.g., decommissioning research) rather than innovation. The maximum fission R&D budget would thus likely be about $200 million per year, with a third to a half devoted to facilities. Obviously there will be no major new federal nuclear development programs and no publicly funded demonstration plants for new reactor designs. What can and what should be done at the new, lower level?

R&D GOALS

The lack of a long run nuclear imperative and the absence of a large continuing nuclear sector undermine arguments for major federal financial support for nuclear R&D devoted to:

A. minor cost reductions in existing LWR designs;

B. expensive infrastructure projects such as the AVLIS program, and

C. continued development work on the next generation of evolutionary LWRs.

The first two R&D projects would make economic sense only if distributed over a large number of plant lifetimes. The third is contraindicated because the ability of LWRs of any type to regain the confidence of the either the utility industry or the public is open to serious doubt, and because LWRs have moved into the private sector and the expenditure of public funds for improvement of a commercial product is hard to justify.

What kinds of nuclear R&D still makes sense? There are strong proponents for:

1. The R&D necessary for the safe operation, decommissioning and waste disposal associated with existing reactors.

2. "Cross-cutting" R&D that benefits both nuclear and non- nuclear energy technologies, such as R&D for high temperature materials, gas turbine technologies, and energy storage.

3. R&D related to nuclear power's potential role as a long run greenhouse hazard and energy scarcity insurance policy.

The first item will be financed primarily by nuclear power consumers and the funding level will be relatively inflexible. The second two areas will compete with each other for the limited nuclear budget. Although the "cross-cutting" R&D will contribute to nuclear power if there is a renaissance, it has a distinctly non-nuclear flavor and is not likely to be lodged in any nuclear directorate. It seems to us that item 3 is the only "nuclear" R&D that has substantial claim to federal funding. We will concern ourselves with the question of whether it makes sense to spend any money at all on this item.

Proponents of item 3 argue that nuclear power must be kept alive to preserve the existing investment and to enable us to deploy nuclear power rapidly if a sudden unexpected need should arise. There are various ways to achieve this end. We can identify four, displayed below in order of increasing funding requirements.

The least aggressive nuclear R&D regime is "preservationist," aimed at preserving the nuclear knowledge base. The "revisionist" regime, geared towards theoretical research aimed at conceiving and developing a nuclear power system that would meet societal needs when and if called upon, would be only slightly more expensive. Much more active and expensive would be "construction modes" involving demonstration plants. The most active are "commercialization modes" aimed at capturing standardization economies and other scaling advantages. Only the first two of these are compatible with funding realities. However, it may not be possible to preserve or extend the current knowledge base in the absence of a healthy nuclear industry. In that case, does it make sense to spend any money at all?

a. Preserve

The industry has accumulated hard won theoretical knowledge and practical experience, drawing on "the best and the brightest" scientists and engineers in its early days and retaining some of the earliest practitioners to the present. Some of this knowledge is incapable of transmission through the printed word as captured in scholarly papers, conference proceedings, text books, government regulations, industry materials specifications, etc. Some of the knowledge is "tacit knowledge," involving modes of problem solving, rules of thumb, intuitions about what not to do, as well as what to do, and memories of unrecorded dead-ends that elude the journals. This kind of knowledge is often transmitted by mentors and requires an on-going R&D program to ensure its survival. However, an R&D program without a clear mission and frequent "reality checks" may not be sufficient.

Historical experience suggests that the absence of on-going construction experience will discourage entry into the nuclear industry by the most talented young scientists and engineers. Those that do enter are in jeopardy of losing their bearings. The absence of feedback from actual reactors threatens to encourage the evolution of "fantasy" designs insulated from the reality check of operating experience and market criteria. The proliferation of "fusion reactor designs" that are cranked out by universities and national laboratories show how easy it is to fall into the trap and how dangerous the process is to the practitioners. The "preserved industry" may reduce to "true-believers," self-selected into an isolated fraternity. It may not be possible to preserve our current knowledge in the absence of a vigorous nuclear program.

In any case, it may well be that we do not want to preserve our current knowledge; it is not clear that current nuclear expertise will be relevant to nuclear projects 30-50 years from now. It is likely that materials breakthroughs, instrumentation advances, and other innovations from broader intellectual domains than nuclear engineering, such as mechanical engineering and computer science, will reshape nuclear technology. It is thus not clear what the payoffs will be to maintaining a sharply focused nuclear power engineering and scientist cohort engaged in ever closer analysis of the present reactor fleet. Nurturing existing nuclear expertise (e.g., in fuel cladding materials) may be akin to preserving vacuum tube expertise just prior to the invention of the transistor or preserving hands on experience with electric typewriters after the shift to personal computers.

The "value-added" of preservationist research is also reduced because some American nuclear R&D is already guaranteed for "technological maintenance" in areas such as decommissioning and nuclear waste disposal, and more important, the existence of healthy foreign nuclear programs. While there is undoubtedly some advantage to maintaining a domestic knowledge base rather than relying on foreign study for our students or on the purchase of foreign expertise if nuclear renewal is pursued in the future, the marginal value of weak domestic programs is reduced in the presence of foreign nuclear programs. The history of LWR development in Japan and France suggests that the penalty for second place may not be high for a country able to mobilize technological resources quickly. In fact, second place may be more rewarding than first place.

Finally, the preservationist case is weakened by the need for any nuclear revival to break cleanly with the industry's history of insular discourse, excess technical and economic optimism, and dominance by short-term commercial pressures. While some impressive changes have been made in the last 15 years, institutional subcultures change slowly. In the absence of external corrections, it maybe difficult to ensure that an intellectual Gresham's law does not rule.

b. Reconceive

The insurance rationale for nuclear power R&D shifts the focus from short-term commercial goals involving immediate market competitiveness to long-term development goals. This shift gives priority to the dynamic (path-dependent) implications of design choices. Nuclear power's historical development path was shaped by military and geopolitical pressures for rapid development and erroneous assumptions about future electricity demand growth and fossil fuel and uranium resource limitations. These factors oriented design choices towards light water and breeder reactors with active, defense-in-depth safety strategies. Recent DOE and nuclear industry R&D agendas are the legacy of these decisions.

Once the priority of short-term deployment and the assumption of long-run inevitability are dropped, different development paths can be considered. We believe that the implicit preference of the public is to start with a demonstrably safe design and to evolve economic competitiveness. Current industry and DOE R&D policies are inconsistent with and indeed are antithetical to these priorities. The Clinton administration's R&D decision rule, for example, calls for gearing energy R&D spending to near-term commercial relevance. Westinghouse and GE have sacrificed full passive safety for short-run economic competitiveness for the AP 600 and SBWR designs. Supporters of the HTGR have flirted with similar decisions (e.g., hesitating to fund expensive quality control and quality assurance programs).

The shift from a commercial to insurance rationale for nuclear power R&D increases the relative value of reactor designs with greater assurance of eventual public acceptance. *Ceteras paribus*, cheaper is better, but what is preeminent in backstop insurance is guaranteed availability. For nuclear power, availability tends to be maximized when public acceptance is maximized, thus extentionist R&D needs to address public concerns about radiation hazards, reactor accident probabilities, nuclear weapons proliferation, and waste disposal:

- Concerns about radiation hazards call for continued scientific study of the mechanisms of radiation damage and large scale epidemiological studies to resolve statistical uncertainties in currently available data.
- Reactor safety concerns call for the development of passively safe reactors able to demonstrate their safety claims experimentally. Illustrative of the type of passive safety R&D projects that may make sense would be work on the thermal hydraulics of the PIUS reactor (geared towards demonstrating the design's ability to avoid excessive shutdowns) and work on MHTGR fuel elements (geared towards demonstrating quality assurance). Because passively safe reactor R&D will be constrained by budget limits, modular technologies that are small enough to be explored without massive funding, and technologies capable of meaningful development without demonstration plants, would be the most attractive.
- It is not clear whether efforts to reduce proliferation hazards can significantly reduce opposition to nuclear power, but increased attention should be given to proliferation safeguards in the post Cold War era. Minimizing proliferation risks mitigate against LMRs, especially designs involving reprocessing.
- In the absence of convincing technical and political solutions to the problem of long-term waste disposal, attention should be given to the development of acceptable methods for monitored surface and underground retrievable storage. There will be sufficient time to examine the question of more permanent solutions.

GREENHOUSE ISSUES

Because the future of nuclear power is increasingly tied to arguments about greenhouse constraints on fossil fuel use, it is appropriate to briefly explore the linkages between greenhouse concerns and nuclear power R&D strategies. The implications of greenhouse hazards for nuclear power depend on three factors:

1. Scientific judgments about the physical impact of greenhouse gases on the environment;
2. The translation of physical outcomes into economic outcomes (i.e., damage assessment); and
3. The availability of non-nuclear greenhouse abatement options.

Uncertainty dominates all three areas and is likely to persist for at least a decade and probably much longer. For example, there are major gaps in our understanding of the feedback effects of global warming (especially with respect to cloud formation and ocean behavior) and the sensitivity of ecosystems to climate change. Uncertainties also abound about the economic implications of greenhouse hazards for a variety of market activities (such as farming) and non-market phenomena (such as species diversity), making damage assessments extremely difficult.

Perhaps even more important for assessing the future of nuclear power are the large uncertainties about the cost of non-nuclear greenhouse hazard abatement options. Those who perceive a nuclear imperative in greenhouse abatement targets appear to neglect these alternatives. In addition to all of the conventional non-fossil fuel supply and demand side competitors to nuclear power (most RETs, DSM programs, etc.), there are a large number of non-nuclear, greenhouse abating technical options, such as increasing forested areas, the redesign of fossil fuel generating technologies to minimize greenhouse gas releases (especially through higher energy conversion efficiencies), engineered CO_2 capture and storage, altered agricultural practices, geoengineering projects (such as efforts to increase atmospheric reflectivity) and so on. There is strong evidence that significant greenhouse gas reductions or offsets can be achieved at relatively modest cost for several decades.

Despite the many uncertainties involved in all areas of greenhouse hazard assessment, some relatively certain conclusions can be drawn about the implications of greenhouse hazards for nuclear power:

a. **It will be difficult to mobilize public support for unpopular energy sector initiatives, such as nuclear power, in the short run (0-10 years)**, due to persisting uncertainties about greenhouse hazards.

b. **Options that are less expensive and less socially contentious than nuclear power are likely to remain available for at least 10-20 years.** Furthermore, because the analyses that find high damage costs are driven by the same kinds of concerns (risk aversion, distrust of technological fixes, ecological conservatism, etc.) that often motivate anti-nuclear power sentiment, it is unlikely that proponents of serious greenhouse risks will favor nuclear responses.

c. **The major value of nuclear power as a greenhouse policy option is long-term,** as a backstop technology, a role for which there are several competitors.

Attention to greenhouse issues, thus reinforces the main thrust of this paper, that nuclear power R&D should be reoriented from short-term commercial goals to long-term efforts to develop a publicly acceptable form of the technology. Given the availability of competing backstop options, greenhouse justified nuclear projects must live within modest financial budgets.

CONCLUSIONS

Technology Assessment and R&D prioritizing is an art. Judgments have to be made about likely technological trajectories amidst incomplete information. Unfortunately there is no simple algorithm for translating data about a youthful technology into a mature industry profile. Technologists with differing technological aesthetics can find different technologies promising.

We conclude that current conditions justify modest R&D support for nuclear power as a backstop technology guarding against energy scarcity and greenhouse surprises. For the time being at least, nuclear power has exhausted its privileged research funding position. Opportunity cost considerations require that competing technologies receive serious funding. Only if these options fail can a case be made for renewed flows of disparately large amounts of public funds to nuclear power. For some other countries, less well endowed with alternatives, an active nuclear R&D program may well be the optimal response, but not for the United States.

In some respects the interregnum, if there is to be a second nuclear era, may turn out to be a blessing in disguise for nuclear power. Many scholars have written about the problem of bureaucratic inertia in general and technological lock-in with respect to LWRs in particular. Even as the nuclear industry winds down, sunk costs in the commercial sector and interlocking subcultures in government bureaucracies and academia, inhibit innovation. A clean break offers the opportunity of a fresh start unburdened by intellectual and emotional bias.

Building consensus for a second nuclear era will require inclusion of technically trained skeptics about nuclear power in hazard assessment studies and design reviews of advanced reactors. Even such inclusion, however, may not eliminate objections to new nuclear plants, due to irreconcilable differences in technological aesthetics between proponents and opponents of nuclear power. It may be impossible, for example, to arrive at a shared definition of a definitive safety test for passively safe reactor designs. Nevertheless, critics with technical expertise should be included in nuclear planning as a means of avoiding insular discourse.

With the drying up of funds for nuclear power we have already seen a burst of creative work at the National Labs and EPRI on non-nuclear technologies. A respite for nuclear power R&D would encourage further reconfiguration of research groups and personal interests. There may or may not be a second nuclear era, but if there is, it will certainly benefit from the opportunity to realistically assess the goals and constraints, both technical and social. The improvements in fossil fuel burning and the potential of RETs has given us the time to think. Luckily, thinking does not require very much money.

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WHAT ROLE SHOULD RENEWABLE ENERGY TECHNOLOGY PLAY AND WHAT WOULD LIFE BE LIKE WITH THEM?

DISCUSSION

U.S. Nuclear Power Industry Professional:

The issue that I want to talk about is one of change, the need for it and the industry's willingness to make it, once it is seen to be beneficial. The previous comments, by both speakers and the respondents, imply that the utility industry is not going to change, that it is closed to improvements, that it is closed to new technology, even that it is closed to the advanced designs. Rather, I think that the industry is opposed to new generations of technology that do not directly address the environmental and safety concerns of the public. I think the best evidence of that was the discussion we had about the need to change the technology, the need to change public opinion. The industry wants to change public opinion by changing the technology.

My comments are made from the perspective of the utility-driven advanced reactor program. So, mine are not comments about particular reactor concepts. We note that each of the reactor designers is serving the world's utility industry, which collectively has been guiding our programs. My perception of the utility industry is that the utilities are very open to new technology; they urge innovative improvements in the designs, beginning with established designs, which are points of departure for the reactors' designers. They have gotten very aggressively involved in pursuing improved safety, other design features that address issues of maintenance costs, and societal benefits such as have been discussed here.

Utilities, in general, have rejected the idea of somehow designing a reactor to have some perceived sex appeal from the standpoint of public opinion. Where then some additional work would be needed to make sure that that sexy reactor would actually work, that it would be efficient, safe, and so forth. The utilities really concluded the opposite; that we must reopen the nuclear option with designs that we are confident are going to perform well, to be safe, and to be economic. They also decided that the design to do this is that of the advanced light water reactor, but one which is very different from the current plants in many respects. These differences include not only design, but the infrastructure that would support it. This approach is anchored in technology improvement. This path does not reject the more advanced designs. Rather, it creates a setting into which the other more advanced designs can emerge in the future. So, I hope that I have dispelled this idea that the industry is opposed to change. It is not.

My second point has to do with the premise that, if somehow we can make future reactor designs radical enough, then we can sell them to the public. I think the reality is the public does not care a lot about technological features. There is evidence of this in some of the surveys of public attitudes that many organizations have done. What the public really wants, and what they expect from a nuclear industry that will have a future, is for the public to have confidence in the institutions of that industry. The public is not interested in specifying the design, or a particular design feature, or a particular choice of fuel or coolant for a new reactor. The reality, I believe, is that all of the advanced nuclear technologies, across the board, are very safe as compared to the competing technologies. None of them is immune to some kind of damage. They are not perfectly safe; none of them are. All nuclear technologies produce some kind of waste. There is not a design that has been invented yet that does not. The point is that all of the advanced designs have a lot of value and merit, and the differences between them are marginal. The idea that if we can just throw out everything that has existed to this point and create a new nuclear power design then everything is going to be fine, is a bit naive.

U.S. Energy Researcher:

Dr. Williams laid out a really broad role for renewable energy technologies in the future. The time scales are also still fairly long into the future for wide-scale commercialization, assuming that you can succeed. My question is that of how would you organize and sustain a research and development (R&D) effort that is appropriate for achieving this success, advancing photovoltaics on the one hand, and fuel cells on the other, and then biomass as a third option? How do you organize an R&D activity that is necessary to have a good chance of wide-scale applications along the lines that you envision for the U.S., and then more globally?

Dr. Robert Williams (Princeton University):

Up until last year I would have said the answer is to pursue the Pacific Gas and Electric (PG&E) model of doing R&D. We learned one of the major lessons of the 1970s and 1980s, which is that the classical model of doing R&D, where it starts in the laboratory—the National Laboratories, where you develop an array of products that eventually will be handed over to industry—just does not work. I was very excited for a while about the PG&E model because it was a user-organized R&D effort. PG&E was not involved in doing the R&D itself. Rather, the venders of the various technologies that were involved in the program were doing the R&D, and the R&D effort was being organized by the potential users. It is a very healthy model.

I was very dismayed this last year, during the last summer, when PG&E essentially eliminated almost all of its energy R&D effort. I understand that the reason for this is the very strong competitive pressures that have entered into the utility industry. What is happening at PG&E in California is by no means unique. It seems to be happening in the electricity industry as a whole, in this and other countries. We have to find ways to resurrect a user-organized R&D effort. I think that one way to do this is to couple a market stimulation effort with the R&D effort.

One of the things on which I am going to spend a lot of time is trying to understand how the pace of photovoltaics energy technology development can be accelerated. One of the problems with the current approach is its focus on niche market development. In other words, you identify applications that are each cost effective, on a project-by-project basis. If you look at the overall potential, or demand growth of this strategy, you see that the demand growth is so slow that the time at which the cost falls below the value of the electricity from photovoltaics is so far away that the electrical industry is not going to be interested in it. On the other hand, if you can stimulate the rate of demand growth, for example, by requiring utilities to hold auctions for mass purchases of photovoltaics, what you are going to end up with is an initial period when the cost is going to be in excess of the value. Because you want to be using a market development strategy it is necessary to find some way of absorbing those initial costs

What seems to be true for photovoltaics and for a wide range of other renewable technologies is that the cost is very small in terms of the subsidy that is needed for that market stimulation effort. Likewise, the R&D effort needed to support the market development effort is small compared to what is required for advancing conventional technologies. What is currently fashionable in Europe, and also starting to be used in the United States, is a focus entirely upon the market stimulation efforts. I think that that is not a very wise strategy. You have to focus on both R&D and the market stimulation effort. In the case of photovoltaics, that is important because the technologies that are likely to succeed in the marketplace are probably not on the market today. Also, the companies that are in the marketing business often do not have the R&D capability.

Journalist:

I think one thing that has to be included in the equation of what is going to be successful in the future is public acceptance Despite the fact that it is hard to believe, many people think of nuclear technology as old-fashioned. Nuclear power today is the technology of the past. I do not think people see it as having a future.

Renewable technologies still have tremendous promise in people's eyes. These technologies may not have fulfilled that promise yet in practical ways, but people still believe in them. I think that this is the big hurdle that nuclear power has to get over if it is ever going to come back. People have to believe that it is something new. That it is not just the old technology jazzed up in some way. If this is not done, I am not sure that anyone is ever going to consider the technology to be new.

I think nuclear power has other problems, too, that renewables may have also, to a lesser extent. We have all seen that people are less and less willing to put up with big plants of any sort, whether they are waste-to-energy plants, hydro-electric plants, or coal plants. Consider the new, very large Hydro-Quebec hydroelectric installations in Canada. I believe that they are so far away that they will not really affect any of us here in Boston. However, even these kinds of plants are having real trouble with public acceptance.

I think that the idea of a distributed network of photovoltaics plants, of tiny little electric generating stations, is an interesting one, if people should believe that these plants are small enough that they are not going to have some catastrophic failure that could hurt everyone, and if they are distributed so they are not in just one person's backyard or taking over the entire state of Kansas with turbines. I think that is something that may disturb the public acceptance, or lack of it, and make for a technology that is more acceptable. I know that Prof. Lidsky has talked in the past of using smaller nuclear plants. I do not know whether that will then lead to greater public acceptance, however.

Prof. Michael Golay (MIT):

I would like to go now to David Leroy, because we have had two arguments brought up: one is that the public in fact is not going to care about the hardware of a power station and its details, providing that they can have confidence in the people operating it; and the other is that they will have strongly held opinions regarding the technology. I would like to get his perspective on this.

Mr. David Leroy (Leroy Law Office):

For three years as United States Nuclear Waste Negotiator I worked in the area of public perception, dealing with the fears of the public about nuclear technology and nuclear waste. I hear the point well made that the public does not have a very detailed understanding of nuclear technology. However, I do not agree with the point that it can take something less than a radical design to reinterest the public in coming back toward nuclear power. It is a basic rule in social science that it is much easier to lose trust than to regain it. The rapporteur observed that in the 1950s the public tended to approach nuclear technology with a trusting and optimistic perspective. This attitude has to be regenerated by some very radical designs that will reinterest the public in the technology. The needed confidence in nuclear power institutions, whether it is the utilities, the scientific community, or the Department of Energy, will not be rebuilt easily. Probably it cannot be rebuilt without some radically significant design changes that will reinterest and intrigue the public in the same way that it was intrigued with the technology in the 1950s.

In contrast, renewable technologies are not perceived by the public as being sponsored by unreliable, irresponsible institutions, even though it may be that their R&D budgets come from some of the same government sources as do those for nuclear R&D. In fact, utilities throughout the country are now sponsoring renewable energy projects, in part, to enhance their public images. I think it will take radical designs to get nuclear power back into the game.

U.S. Government Employee:

There was a perception raised by Dr. Williams which I would like to clarify in relation to the DOE budget. When I learned this, the result of that was rather striking to me. The comparison of the 1993 R&D budgets between nuclear power and renewables was $183 million to $686 million, respectively. This result is, of course, quite different from what we were presented by Dr. Williams a few minutes ago. The other point arises from a question that Senator Johnston very perceptively asked a few month ago about how much money the Department of Energy has spent on energy research for all kinds of energy technologies. It is sort of an embarrassing question, in a way, because the DOE did not have the answer. The answer was that from time immemorial we have spent $11.6 billion for fission, fusion sits right up there at $7.5 billion, and we have spent $9.9 billion for renewables. The renewable number, of course, includes tax credits, which I think is fair. They comprise approximately half of the renewable total.

I certainly do not object to spending money on research and development on renewables. But, I think we ought to understand where we stand here. Nuclear energy produces 22% of our electricity. The kind of renewable technologies that we are talking about here produce instead an extremely small percentage.

Public Policy Analyst:

Well, there are also, of course, the questions of indirect subsidies, of the public stuck with the bill for nuclear waste, and also the question of who will pay for the next accident. Realistically, when we consider such questions, we are talking about how this industry might be revived.

There is really only one way. And that would be if this industry did a thoroughly convincing and spotless job of cleaning up from the first generation of reactors. I think that the public perception is that the first generation of reactors has failed, and has made a hell of a mess. Further success would also require that this first generation of reactors go to final shutdown without another major accident. That is a *sine qua non*. Without it there will be no second generation. I do not believe there will be one anyway. Participants here are assuming there will be a second generation of reactors.

Concerning the renewable energy technologies, they are now in an either/or position with respect to nuclear power. We have hands-on experience with the Sacramento Municipal Utility District, which in June of 1989 voted by referendum to shutdown the Rancho Seco nuclear power station, and which is now going directly to using renewables. With efficiency increases and with some help from the grid, by the year 2000 they will be very much independent. According to the general managers of their program, it is now ahead of schedule and under-budget. We are now having a similar situation arising in Minnesota, where there is a grassroots movement to shut the Prairie Island nuclear plant in exchange for the enactment of a defined program to put Minnesota pretty much on a 100% basis, relying on renewable energy technologies, especially upon biomass and wind. The driving force in the Minnesota movement is nuclear waste. The industry [Northern States Power Co.] is attempting to build a dry cask storage facility [at the power station site] in the middle of the Mississippi River next to a Native American reservation with all of the political baggage that that implies. I think this is very much the way of the future, and it shows why we believe that the future lies with renewables.

U.S. Nuclear Power Industry Professional:

Prof. Lidsky used the word reconceptualization. I think that we have to give Admiral Rickover credit for conceptualizing the first generation of nuclear power, and he did a hell of a job. In a submarine where space is at a premium, we must have a high energy density in the reactor. I think the earlier days of nuclear energy were typified by high energy density in the naval reactors, and for the navy the cost was much less of an object.

However, if I were going to conceptualize a nuclear power plant today, where the prime attraction would be on safety and costs, then your criterion for standardization is somewhat different. First of all, you would no longer have to have the very high power density core that potentially underlies some safety problems. Number two, you probably want to have materials that are non-corrosive in order to avoid the cost problems of corrosion and chemically mobilized radioactivity, which can also lead to safety problems. So, you would want to use chemically inert coolant, if possible. Number three, in the interest of cost you would want materials with very high tolerances of high temperatures; because only at high temperatures can you maximize the thermal efficiency. So, in reconceptualization, perhaps we should look beyond the ideas of Admiral Rickover.

Public Policy Analyst:

I think that I also recall that in the 1960s Admiral Rickover advised the Congress that we would be wise not to pursue development of nuclear energy if we did not also have solutions to radioactive wastes. I am struggling on my state's advisory committee with even finding a place to put low-level radioactive wastes, without worrying even about spent fuel and other high-level waste management.

I would like to ask Dr. Williams a hypothetical question. Let us say that I am a state public utility commissioner facing this terrible headache of unhappy rate-payers objecting to increased costs for spent fuel management, for radioactive waste disposal, for repairs of reactors, for a number of other aspects of electricity costs. I would like you to advise our public utility commissioner on the best mix of strategies with respect to the alternative energy technologies that you have proposed, combined with energy conservation—about which we really have not heard anything today.

Another aspect of efficiency improvement is to show us how our state can put together a plan which would satisfy our customers at a reasonable cost, and which would take us where you would want us to be technologically within a reasonable time limit. Secondly, I would like to ask the same question playing the role of a county commissioner who would like to develop a community-based, much more localized energy system to satisfy as much demand as possible, using the small scale energy technologies that you have proposed.

Dr. Williams:

I will just comment very briefly. First of all, as far as renewable energy technologies are concerned, you cannot at the present time have a cost-effective diversified portfolio of energy options on the same utility system. Wind power can probably be included in these deliberations if you are in a suitable state. There are many parts in the United States where there is a large wind resource; so, that makes a lot of sense. Biomass technologies, as Mason Willrich has pointed out, have been very successful over the last decade. But, use of those technologies is not going to grow based upon existing technology. We need to have advanced biomass conversion technology. Those are just now being demonstrated; it would be the turn of the century before you could buy one.

As far as photovoltaics are concerned, the key is to find a way to come down on the learning curve very quickly. I do not think that that issue is going to be decided at the state level. It really requires much more concentrated effort. One of the reasons is very fundamental; it is that the costs are going to go down with growth of the overall market. What you want to do is not only to have the states working together, but to have all the countries working together to create as large a mass market as possible. This is because the current costs are functions of limited production capacities.

Academic Socio-Technological Scholar:

I am a little bothered by the turn that the conversation has taken after the initial presentations. This is mainly because of the lack of focus on what I thought might be interesting to discuss here, which is the question of alternative futures, instead of alternative pasts. We are doing a lot of talking about alternative pasts. I am actually going to go to the past for help in thinking about alternative futures, say to 1950, where we had an intelligent proposal from a department of railroad engineering which wanted to remove some cars from the city and to install tracks everywhere. Opposed to putting in such a rigid sort of railroad system were advocates of a technology that no one supported called the automobile industry. This was a technology that is flexible, adaptable and with low front-end costs. Looking in retrospect, it is amusing to think about what those opponents would have said, what in fact did say, in the 1950s, which is why the tracks were taken out.

The question we are examining really has to do with the next generation of nuclear power technology and proposed alternatives. Again, I see an excessive focus upon the economics and the competitiveness, which is a focus upon the economic benefit of your next dollar of investment in R&D. But, it is not thinking about what really is going on, which is building two or more possible alternative future energy infrastructures that are systematically different. The point is that there are costs associated with any of these futures, including nuclear energy futures; just as there are costs associated with distributed energy technology systems. For example, just consider the costs of land-use, or of reorganizing the energy system.

I have no more understanding about the possible costs of a future nuclear energy system than I had when I came here, which perhaps was something I should not have expected to learn. Rather, I have also discovered that people think that if the reactors are small or managed better, or if they get public acceptance, then something will change for the better. However, that does not answer the question to my mind: why change the technology? The implicit reason advanced here is that somehow to have public acceptance, the nuclear engineering organization will profit from it because they will not go out of business, or the companies that design the reactors will be able to build them. It would be nice to know why one should go ahead and change the technology other than for the sake of avoiding past mistakes again. I really do think that in some sense the essence of the decision must be made consciously; I think more consciously by the public than many people realize. There is a lot of intelligent awareness among the public than there was twenty or thirty years ago; awareness of the social commitment that you make with technology choices. However, there is not much presentation of information to the public to support in depth public choices. There is not as much as I think is warranted by the problem itself.

Prof. Lawrence Lidsky (MIT):

The best reason to develop a new reactor design is that the current designs are not working. Something different and better is needed, and evolutionary solutions will not provide the answer. I remember when I was working on my doctoral thesis. Just as the transistor was coming out, RCA was saying "let us not jump too fast." Instead they developed the most cunning little vacuum tubes you have ever seen in your life. I forgot the names of these tubes, but they were vacuum tubes, and when placed in competition with transistors they were blown away. There is a limit to how far you can take a technology before you have to jump to something new and different.

Also, I firmly believe that the public is more than capable of understanding the technological basis of a new reactor concept. If they cannot understand it right away, it is the job of the technologists to explain it to the public. If the technologists cannot explain things to the public, it is not the public's fault. Also, the public does not have to be rational. That is one of the great benefits of democracy. But, the public will understand, although it does not have to believe. You had better have a new technology that is simple enough to explain to the public. Doing this is a part of the success equation. You cannot just create the best possible reactor. Rather, you have to create the best possible reactor that the public will accept. However, let me come back to my answer, which is as simple as the question. The reason we have got to fix the reactor technology is because it is broken.

Academic Socio-Technological Scholar:

I want to address the associations with nuclear energy including associations with the bomb. Nuclear energy and all the things that are associated with it makes it extraordinarily difficult to develop a new design which the public will accept because there were two counts against them from the very beginning. The general public, in fact, do not constitute the people who you have to persuade to accept nuclear power. You have to persuade the top of the critical elites. The critical elites are the people who have to be persuaded. They are those people who form public opinion. I am talking about the media, public interest groups, and so on. It is my persuasion at this point that no dialogue is going to be very effective concerning this issue. This is because people's attitudes have become very fixed and unchangeable.

Let me give you one example: I have heard some comments here about dangers of ionizing radiation, dangers from radiation from nuclear plants, and these are supposed to be real problems. Now of course obviously, everyone here knows that with ionizing radiation, the dangers depend very much upon the amounts of such radiation exposure. Without knowing this, estimates of dangers are meaningless. Some colleagues and I conducted a randomly sampled poll involving cancer epidemiologists for a study we are doing on environmental cancer epidemiology. We conducted a poll of media coverage of cancer; it was as much a study of media as of media coverage. We conducted studies of the most important environmental groups in terms of frequency of mention by the press. Let me give you a wonderful line: According to the random sample of cancer epidemiologists, a group selected so that they have no interest in nuclear energy, it is not their field, they make no money from it, they are computational experts, they say that "the dangers of radiation nuclear plants are minimal, negligible as compared to diet fats, sunlight, smoking, never important on any scale that you can use."

However, if you turn to one of the public interest group leaders, the majority think that the dangers of radiation from nuclear plants are very considerable. They ought to know better. These are people in such groups as The Sierra Club. They are very intelligent people; they are not idiots. Where do they get their views about the dangers of radiation from nuclear power plants? I am not expert enough to know, but it seems to me that you find out what the scientific community believes. I can tell people until I am blue in the face about what the scientific community believes. It will not change a single mind; I have tried it. So, I think you are whistling in the dark hoping for a change in public opinion. I do not think that a new generation of nuclear power plants is going to persuade people that nuclear energy is a viable option at this point. Sorry to be so pessimistic. I do not have any spite.

Journalist

Oh, absolutely, it is not just the press that is inconsistent, it is everybody. I do not know how many of you know that Brazil nuts are radioactive. They are highly radioactive. I did a story about this for National Public Radio several years ago. In fact too, they are high in radium because they grow in soil in Brazil that has a fair amount of radium, and which is devoid of barium. The trees there are looking for barium, and instead they soak up all of this radium. Their leaves are radioactive, the bark is radioactive, and the water is radioactive; so are the nuts. The FDA knows this. The nuts are, in fact, ten times more radioactive than the limit on radioactivity that was allowed in produce coming from Europe after Chernobyl, but no one does anything about it. Everyone laughs about it, and it is great for cocktail party conversation. Why? Because, it is natural that those nuts are radioactive. However, if there was a nuclear power plant down the way from the plantation, the public would never put up with the same situation. If I put that report out on NPR, you would have seen it on the front page of the *New York Times* the next day. This is our inherent irrationality, which I think is the problem. I am not defending it. I think that it is true that there are definite hazards from sunlight, and there are definite hazards from other things that are natural, such as radon. But, people do not take it as a serious hazard. Radon and renewable energy sources are natural. Everyone loves sunlight. Everyone loves waterfalls, but people do not like meddling with nature. We are just irrational.

U.S. Energy Researcher:

No matter how hard I try, I am pessimistic. My pessimism is connected to a word that has been mentioned several times—the word trust. The fact is that once trust is lost, it is very difficult to regain. Everybody knows that from common experience, and the scholar knows it. So, we all agree with that. Now, the nuclear power people did not lose the trust all by themselves. It was all connected to the nuclear weapons business. I agree with several comments made earlier today by Prof. Socolow and by Mr. Willrich. They pointed out that there is a broadly spread responsibility, even though the nuclear community is not responsible for weapons. The fact is that for many people, including my educated friends who are not nuclear people, some are doctors, lawyers, professionals and professors of various kinds, reactors are linked to nuclear weapons. We cannot avoid that link. The loss of social trust is partially due to that link.

I am going to give you one quick anecdote. I travel around the country a lot. There are three places that are clearly more prone toward nuclear power than any place in the country.

They are around Oak Ridge, the Hanford Reservation, and in New Mexico. You go there and you find out that the Department of Energy (DOE) has lost their trust. I shall tell you why. It is because only today the DOE has just quit lying to the people of New Mexico, as it has been doing for more than three years, about WIPP, and everybody in New Mexico knows that that is what has been happening. For three years the DOE has lied to them about how they needed to get waste down to the WIPP to do tests that everybody knew were junk. And just last week, the DOE finally said that the tests were not needed. Those lies made at will lost the trust of people in New Mexico, people who are intrinsically pro-nuclear, people who are like me, like all of you, who are wanting to try to do things that keep the nuclear power option open.

At Hanford they were lying. I chair a committee of the National Academy of Sciences where Thomas Grumbly, the new assistant secretary of energy, appeared. For the first time he told the truth for the DOE, which is that the promise made by the Department three or four years ago around the country to clean up the DOE weapons sites of all their weapons-related contaminants could not be accomplished. What he really said was that the total bill to clean up those sites under the current plan is $1.1 trillion. He said that publicly. Now, if that is true, and I guess that the stated amount is probably low, the DOE is going to have to go back on the promises that were made to the people, promises signed by the governors, and signed by DOE. That loss of trust is coming, and it is going to be on the plate of the nuclear power business, like it or not. It is going to be another thing that the nuclear power business is going to have to recover from. I do not know whether that is possible. So, I want to tell everybody in this room that it is my view that we are all being painted with the same brush as long as somebody with a nuclear hat on his head is lying to the public. They are still doing it, and you will all pay. We are all paying, and frankly we deserve to pay, as horrible as that may sound—because we are all painted with that brush. It remains our responsibility to see to it that the nuclear people behave honestly, and not only to find errors but to correct them. To do this, we need to be honest with ourselves and with the public. Correcting the loss of trust will not fix the nuclear enterprise, but not correcting it will doom it.

DINNER ADDRESS

FACTORS AFFECTING THE NEXT GENERATION OF NUCLEAR POWER

E.C. (Tip) Brolin, Deputy Director
Office of Nuclear Energy
U.S. Department of Energy

INTRODUCTION

DINNER ADDRESS

In the United States the greatest role in nuclear and "alternative" energy research is played by the Department of Energy (DOE). For that reason we wished to include in the Conference a presentation of the nuclear energy research program of the DOE. This presentation was made by E.C. (Tip) Brolin, Deputy Director of the Office of Nuclear Energy, who at the time of the Conference was the highest ranking member of the DOE staff dealing with nuclear power research. The presentation was made following the Conference banquet. A question period followed by presentation, but a discussion period was omitted, as the attendees were tired after a hard day's work.

DINNER ADDRESS

FACTORS AFFECTING THE NEXT GENERATION OF NUCLEAR POWER

E.C. Brolin

First, I would like to thank Mike and the other people who are responsible for today's sessions. They were very enjoyable. I find it quite boring to talk to people who think as I do all the time, and I certainly was not bored today.

I will make this talk brief because, at this time of day, I know all of you are not interested in staying out too long. To begin, I wish to remind you that nuclear power is a significant part of our current environment.

I believe the most important piece of energy legislation passed in the past several decades was the Energy Policy Act of 1992. Although there are many elements of the Act which I will not mention here, I want to bring to your attention several highlights. One important point is that, although there was extensive debate, in which I am sure many of you participated, the Act passed with strong bipartisan support in the Congress. The Act is, therefore, a true statement of the Congress's intention.

In my view, the Energy Policy Act endorses nuclear power. It lists a number of advanced reactor developments which Congress directed us to continue. It appropriated no money, however, leaving us in a classic situation in which we have authorization to act without the resources to support our activities.

In some cases this does not matter. For example, when the more predictable reactor licensing process becomes law, no money will be needed. However, when you must provide a choice of advanced reactors, for which all research is to be completed by 1998, you must have some funding. This necessary funding was not provided, of course. In reality, it was not requested forcefully by any recent Administrations.

The Energy Policy Act also supports the choice of Yucca Mountain as a high-level and radioactive waste disposal site. And of course, it established the United States Enrichment Corporation, which is a step toward privatization of the enrichment enterprise.

It is important to understand what the Administration's budget does and does not do. In reality, it is not what I would call pro-nuclear or anti-nuclear. If there is to be an Advanced Light Water Reactor program, we need to recognize what the next step in the U.S. nuclear power program should be. There has been no reduction in funding for this program, which is fully supported by the Administration. This support is extremely important to our utility colleagues, I know, as well as to the rest of you who are interested in the future of nuclear power.

There is another item which was debated in the Administration and Congress over the summer. Four hearings were held on the subject of nuclear fuel recycle research. Obviously, given today's discussion, this subject is highly controversial. Congress actually increased the funding that the Administration proposed for this program. The amount the Administration proposed was considerably less than might have been proposed by another Administration, but it is important to note that the program was included in the budget. The Administration, however, did eliminate the advanced reactor programs. That is, they eliminated funding for all work except for that associated with the light water reactor. Consequently, no Advanced Liquid Metal Reactor (ALMR) design activity was included in the Administration's budget proposal. Likewise, no Modular High Temperature Gas-cooled Reactor (MHTGR) activity was included. That clearly was a change and a negative signal.

The funds cut by the Administration for ALMR and MHTGR design and development, were proposed for other purposes within the Department. If the congressional committee report passes tomorrow, Congress will have restored money for the MHTGR design activity. Frankly, however, the words pertaining to the ALMR in the Congressional report are less clear. Congress also provided $110 million for shutdown of unneeded facilities. In addition, funding was provided for those space nuclear power activities that are considered necessary to support space missions such as the Cassini mission (to be launched in 1997), for which we are providing radioisotope thermal electric generators. The space nuclear power reactor project

(SP-100), however, was canceled. These are some of the issues which, I think, will affect the future of nuclear power. I believe there is a similarity between their treatment and the ideas we saw proposed today.

Let's talk about nuclear waste management for a moment. Without progress toward solving the nuclear waste management problem, I do not believe there is much future for nuclear power. The budget supports characterizing the Yucca Mountain site and using a voluntary process for monitored retrievable storage. Also, the Secretary of Energy has indicated she is in the process of reviewing the whole program to see what should be done to keep this program viable in the future.

Figure D.1 shows a picture of Yucca Mountain. Figure D.2 shows a photo of the view inside the excavation. Currently, the work is proceeding in parallel with the debate and the ongoing studies to determine the best form for the long-term waste program.

I also wish to discuss actinide recycle. Figure D.3 shows spent fuel production rates during the years 1990-2030. The dotted horizontal line represents the legislatively-mandated capacity of the Yucca Mountain site, which is 70,000 metric tons. One projection illustrates the amount of spent fuel that would be deposited in the repository with no new nuclear power plant orders or plant life extension, in which case nuclear would not maintain its current 22% of generated capacity in the country. Around 2013, the spent fuel buildup reaches 70,000 metric tons (63,000 metric tons is the actual capacity set aside for civilian waste). Therefore, by the time Yucca Mountain opens, it is fully committed. In fact, as shown in Figure D.3, the amount of waste that would be generated without new nuclear power plant orders or plant life extension *also* exceeds 70,000 metric tons by 2015. So Yucca Mountain by itself is not an answer, even if the use of nuclear power does not continue at the current level. Options for dealing with this problem include extending the capacity of Yucca Mountain or constructing a second repository.

One of the things we are looking at to address this problem is the actinide recycle concept. Figure D.4 illustrates how the concept would work in an integrated ALMR Actinide Recycle Synergistic System. DOE's Actinide Recycle program uses pyroprocessing, a process in which light water reactor spent fuel is chemically reduced from oxide form into metal uranium, transuranics such as plutonium, and other fission products. These materials can be used to fuel a liquid metal reactor. In other words, two processes are being developed through several programs. The first is the reduction of the spent fuel oxide to a metal form. The second involves recycling the metal fuel by taking the plutonium metal from the first process and using it to form fuel for an ALMR. This is the integral fast reactor fuel cycle concept. The metal fuel has been demonstrated to have a long life. The ALMR development work was not part of the Administration's proposal, but the two processing-related activities were funded in the Administration's budget proposal.

Figure D.5 illustrates the actinide recycle concept. Fuel is chopped up and put into an electrorefiner. The electrorefiner is only 12 feet high and would actually fit comfortably in the corner of a small room. An engineering-scale demonstration electrorefiner has been built at Argonne National Laboratory-West. That size machine would support a 400-600 MWe plant with no redundancy.

Figure D.5 also shows the fuel processing system, in which the metal fuel is electrochemically transferred using a molten salt solution. The uranium is collected on a solid metal cathode. The plutonium is recovered in a cadmium cathode. After the salt is driven from the cadmium by heating, new metal fuel can be cast and put back into the reactor.

This is the process Argonne developed, in addition to the long-lived metal fuel, which may be an economical and technologically feasible way to recycle fuel. The Department's R&D program is designed to demonstrate this feasibility by the end of 1997. There are divided opinions, however, on whether the technical and economic feasibility can be proven.

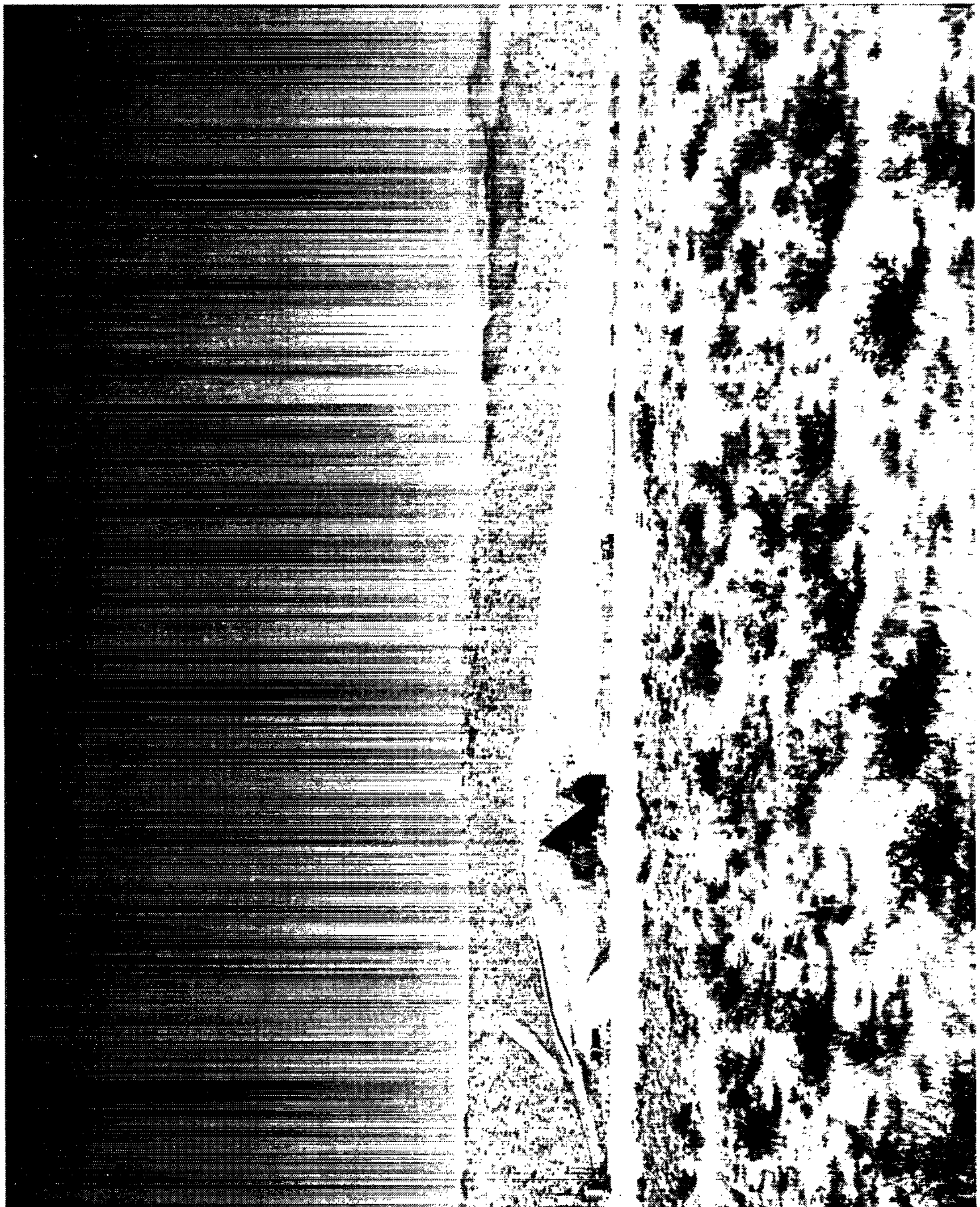


Figure D.1: ESF Surface Facilities Close-Up From Midway Valley Camera Stand.

Figure D.2: Night Shot Of ESF Starter Tunnel, View From Portal To W.P. Face.

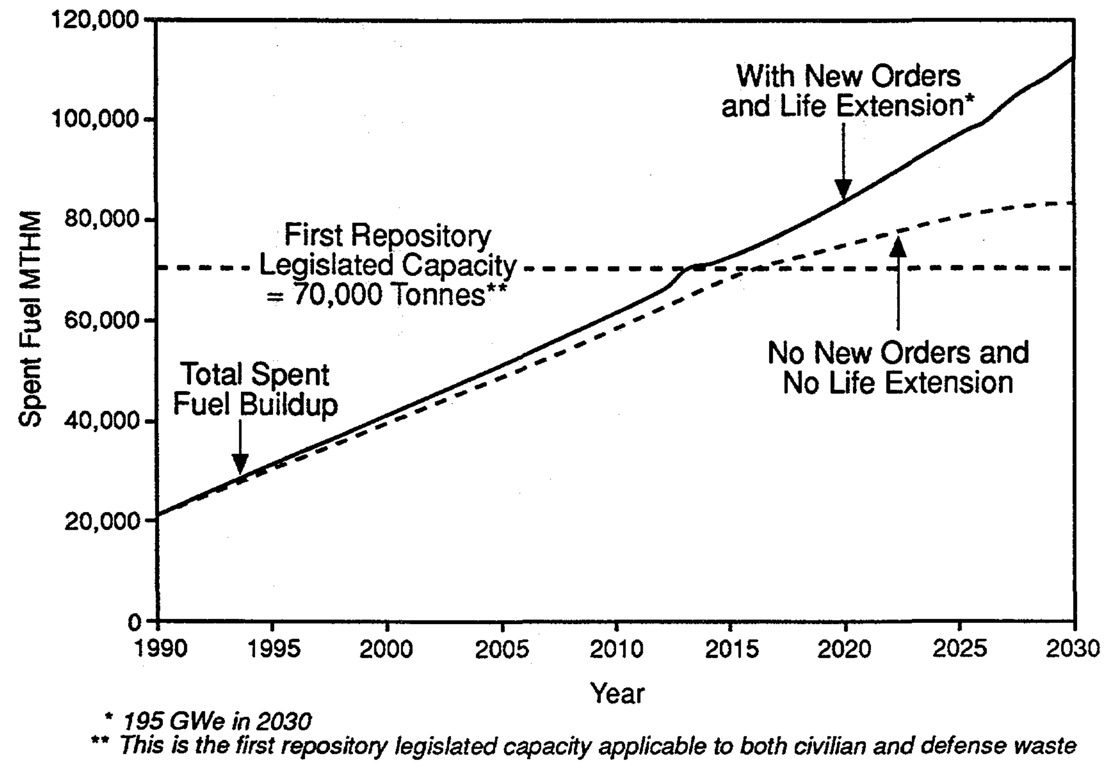


Figure D.3: Spent Fuel Buildup From Mix Of Reactors On Once-Through Fuel Cycle.

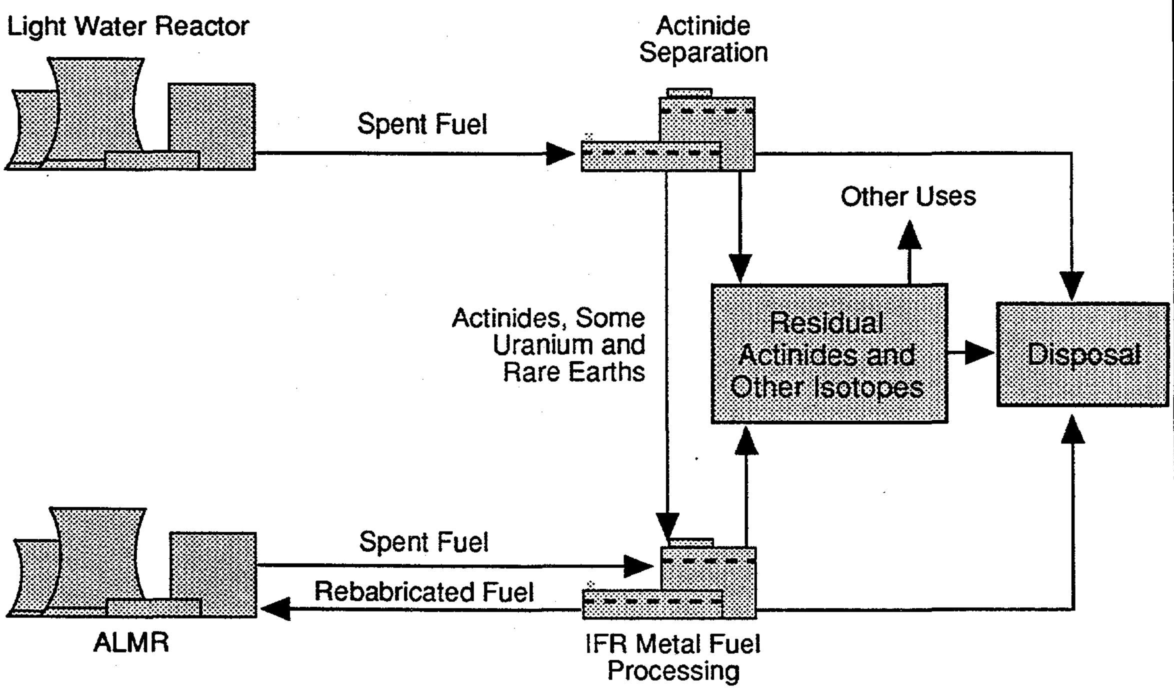


Figure D.4: ALMR Actinide Recycle Synergistic System.

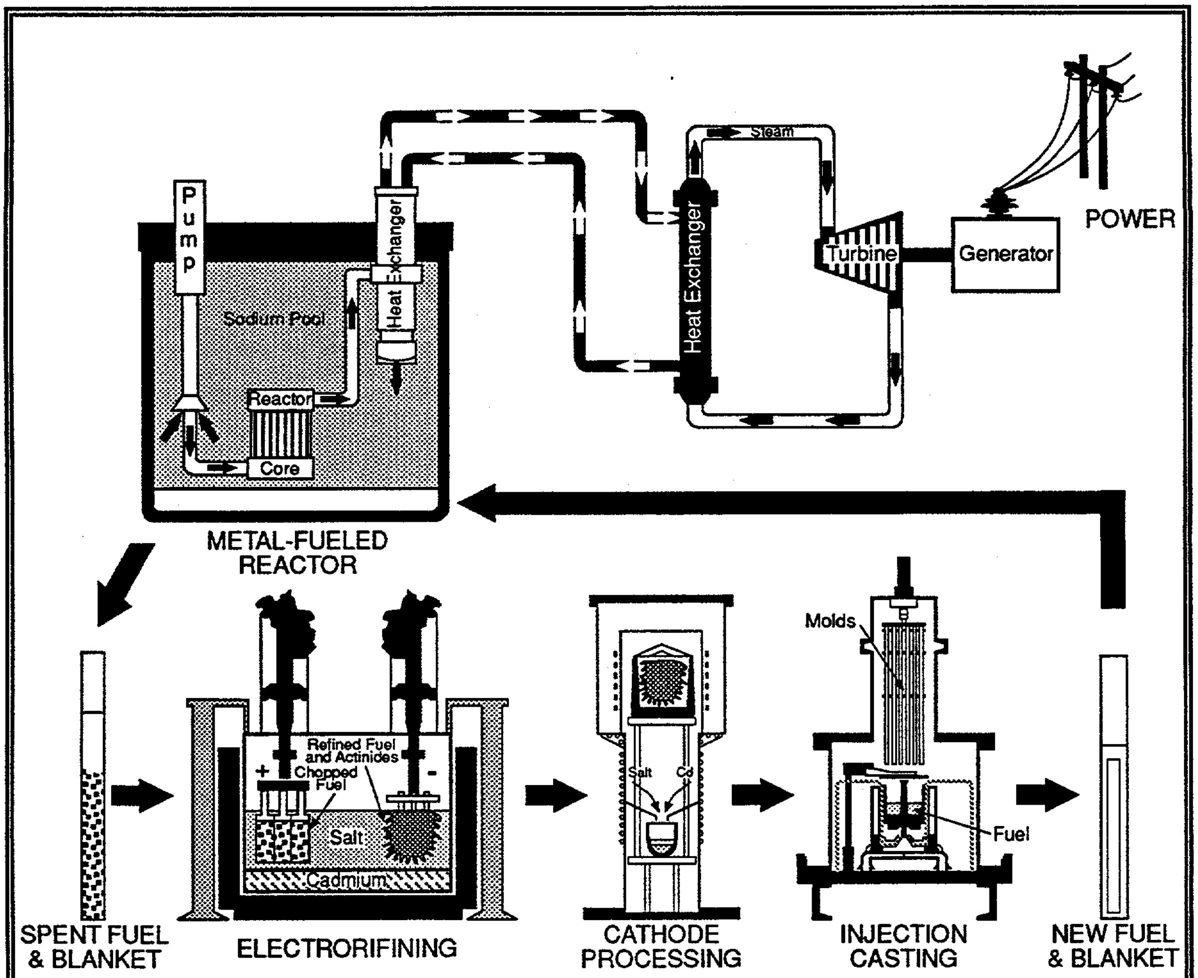


Figure D.5: Actinide Recycle Concept.

We talked about economics today, and I think we need to throw a few kudos at the commercial nuclear power industry. The rate chart in Figure D.6 shows the progress made between 1980 and 1992 to increase the average plant capacity factor and to reduce the number of unplanned scrams; the number of radiation exposures, the industrial safety accident rate, and the amount of high-level waste produced. This rate chart reflects extraordinarily good performance, which is one reason why fifteen of the top-rated twenty nuclear power plants in the world are U.S. plants.

The rate of improvement shown in Figure D.6 deserves some explanation. If you look at the data for operating nuclear power plants and compare the percentage of plants with production cost below the generating cost of the alternative, you see that, as shown in Figure D.7, 85% of nuclear power plants are achieving production costs of less than generating costs of new gas combined-cycle plants, and 94% less than the generating cost of coal plants. Thus, for most utilities, continuing to operate existing nuclear power plants is more cost-effective than building and operating new gas combined-cycle or coal plants.

Let's look into the future. Figure D.8 shows several estimates of generating costs for various options in the year 2000, including the evolutionary ALWR, the passive ALWR, coal plants, and gas combined-cycle plants. While I would not say these numbers are exact by any stretch of the imagination, the conclusion I would draw from this chart is that various people are projecting that new nuclear plants are going to be competitive with coal and gas combined-cycle plants. It is a possible future scenario. We will not know until we get there.

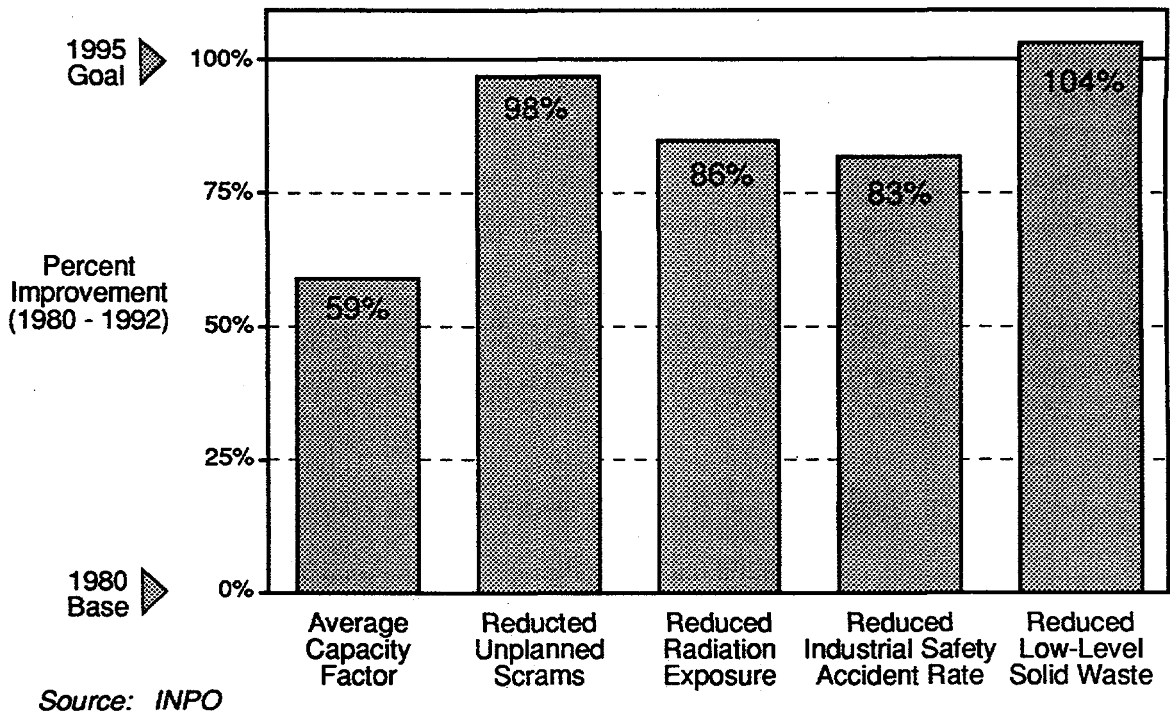


Figure D.6: Current LWR Operating Experience Shows Improved Performance.

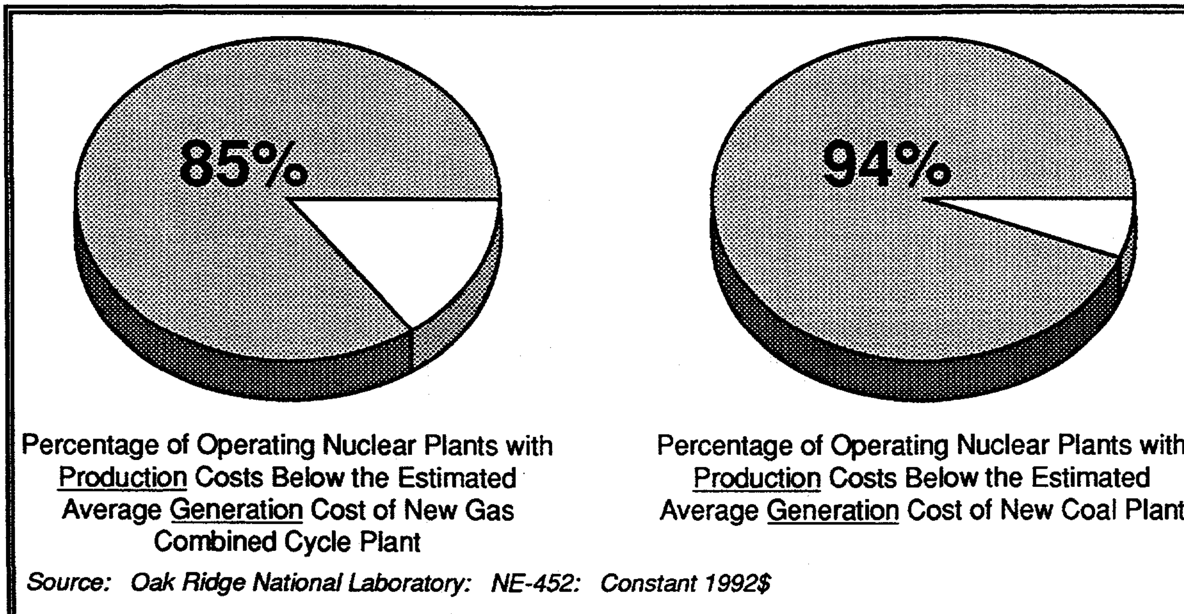
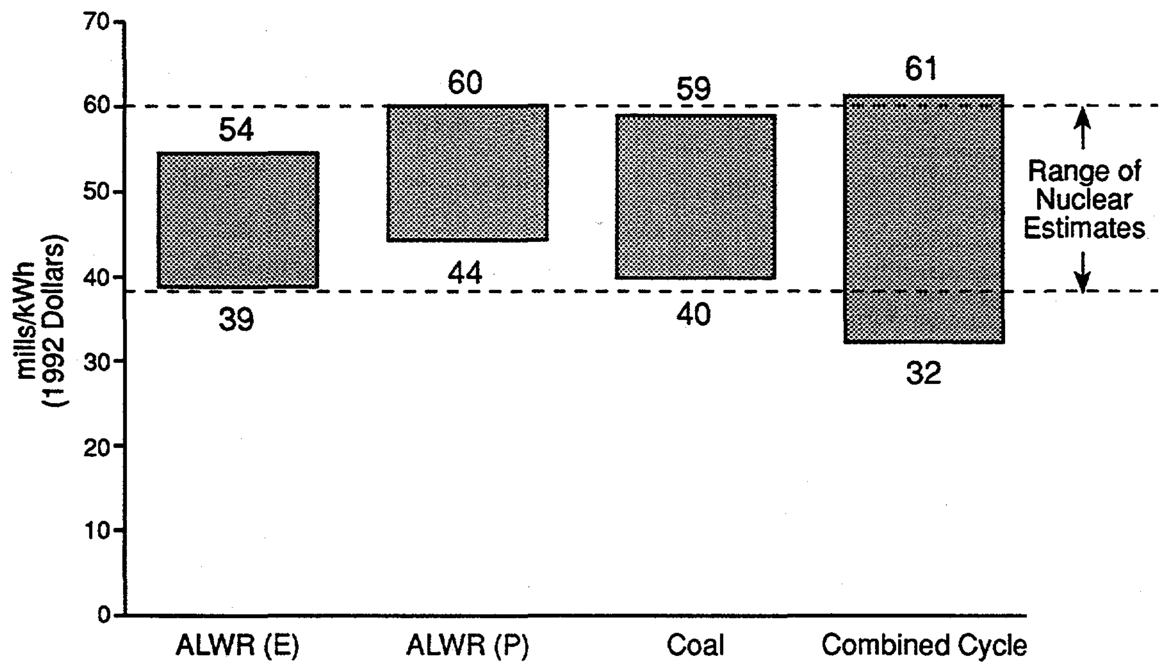


Figure D.7: Continuing To Operate Existing Nuclear Plants Is The Most Cost-Effective Option For Most Utilities.

One of the reasons why the 600 MWe passive plant has the possibility of competing with the 1200-1300 MWe evolutionary plant is found in Figure D.9, which shows system and component reductions from the passive plants as compared to the alternatives. The evolutionary passive ALWR plants have increased safety margins primarily because the thermal margins are increased by 25%, hot leg temperatures are lower, the latest human factors approach to control room design has been incorporated, etc.



Sources: EPRI, USCEA, Enron, Utility Requirements Document

Figure D.8: Generating Cost Comparisons Support Maintaining The Nuclear Option.

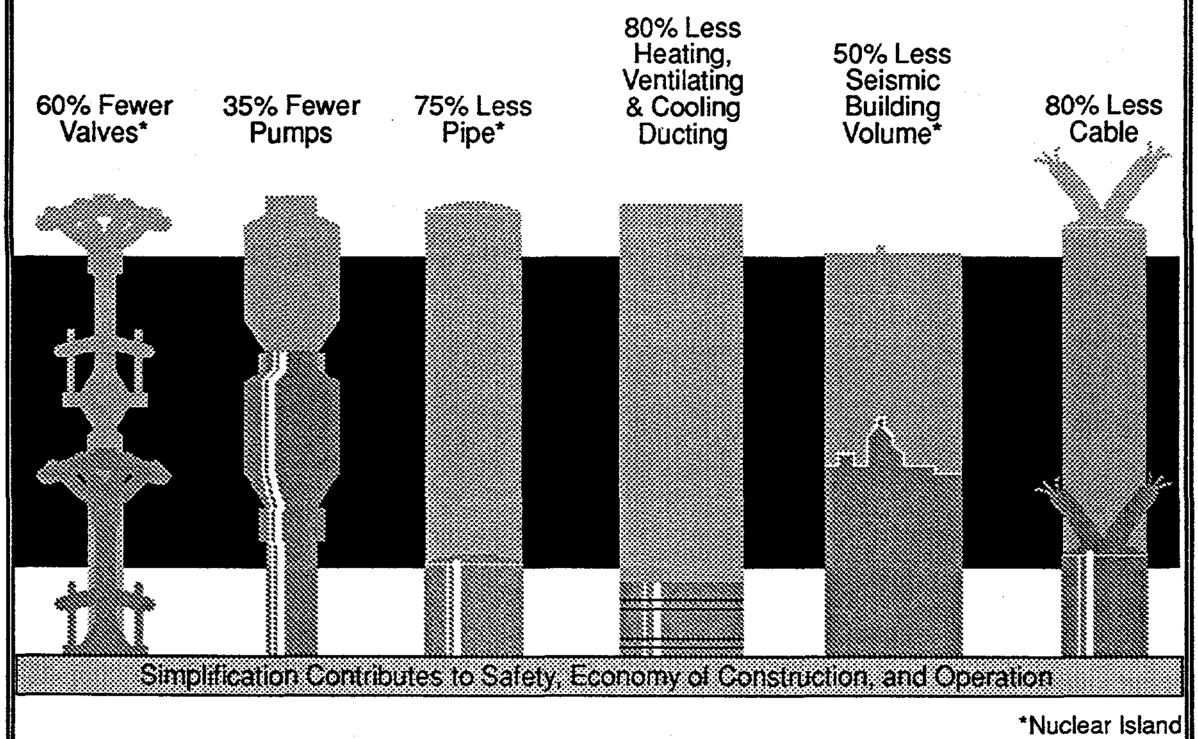


Figure D.9: Representative Reductions From ALWR Passive Plants.

You might be interested in how the passive safety systems work, and how they differ from the conventional evolutionary plant. Figure D.10 shows a main coolant pipe break leaking primary coolant. What we have here are four systems of core make-up tanks, which are actuated using an uninterruptable power supply. They supply makeup water as the coolant leaks out. They are activated in stages. We have on-line 700-psig nitrogen-loaded accumulators that are actuated after the plant is depressurized. The final source of replacement water includes a large containment storage tank which drains by gravity, filling the whole containment to the level of the reactor nozzles.

As the reactor continues to generate decay heat, the water boils and the steam condenses on the inside of the containment building. The containment building is cooled by spraying, which is gravity-fed from other tanks. In the event of a severe accident, this provides 72 hours of water supply, without operator intervention, versus 20 minutes in the conventional plant design. These tanks, of course, are fillable from outside the containment building. We hope this system will never have to be used; but if needed, it is more passive than the other systems used in reactors today and solves one of the problems which I have worried about since I was a nuclear engineer—the need for electrical power when a plant has an accident.

Obviously, from our discussions today, emissions of greenhouse gases and toxic chemicals to the atmosphere as a result of energy production are an important problem facing the Nation. Figure D.11 shows one example of how nuclear power can impact the environment by displacing chemical emissions into the atmosphere. This shows 500 million tons of CO_2 displaced by U.S. nuclear power plants in 1992.

Figure D.12 compares what opinion leaders think about nuclear power, what opinion leaders think the *public* thinks, and what surveys show the public *actually* thinks. As shown, 72% of opinion leaders think nuclear is somewhat or very important to America's future energy needs, and 73% of the public agree with them. What opinion leaders believe the public thinks about nuclear power, however, is the reverse. This is a fascinating chart. It is not too surprising, given the debate that has taken place on nuclear power, but I was very surprised to see the degree to which these categories differed.

In summary, nuclear power has been demonstrated to be environmentally sound, in that it causes no toxic air emissions or greenhouse gases. It can cause radioactive emissions, and it does generates radioactive waste that has to be dealt with. It is hardly environmentally benign in that sense.

Our research and development programs at DOE deal with the next generation of plants, as well as the actinide recycle concept. The next generation of plants, I believe, will offer improvements in safety and economy over currently operating plants. They will incorporate thirty years of experience in the utility industry, which is extremely important. They will be standardized plants, correcting what is, in my view, the nuclear power industry's largest single error of the past. Every plant was custom-built; in hindsight, it is clear that the custom plant approach lead to problems that will be avoided by the use of standardized plants. Neither the utilities nor the engineering contractors have the capability to manage design and construction of 25 differently designed power plants at the same time. I think everyone recognizes this now. Therefore, the standard plant approach is the basis for the development program, which is a great step forward. In addition, it should be noted that all of our ALWR programs are more than 50-50 cost-shared with the industry. In the case of the commercial standardization program, this represents $170 Million of private industry contribution plus $100 Million of government contribution, which is quite remarkable.

That concludes my presentation; I will be happy to answer questions now.

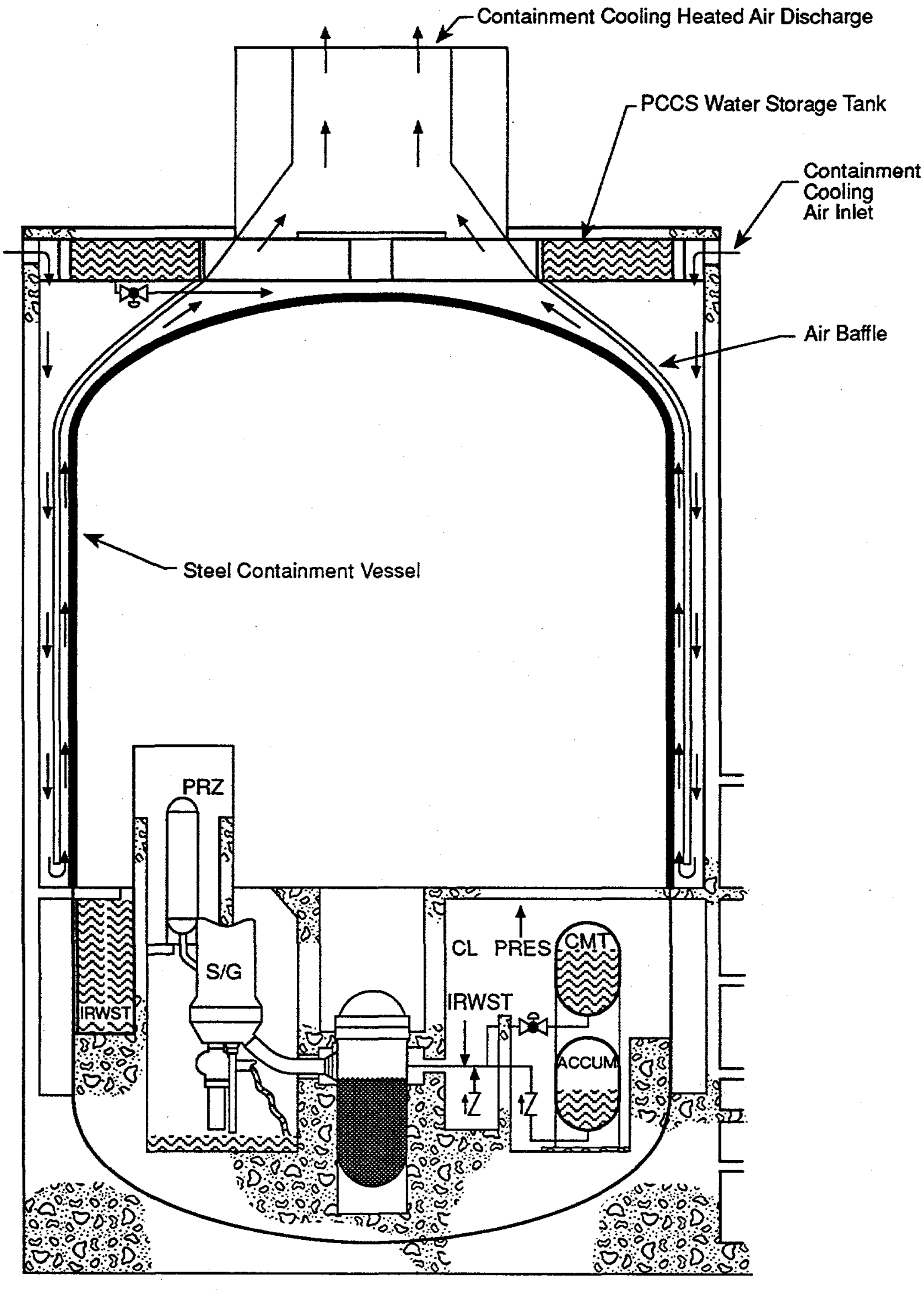


Figure D.10: AP600 Passive Safety Injection LOCA Initiation.

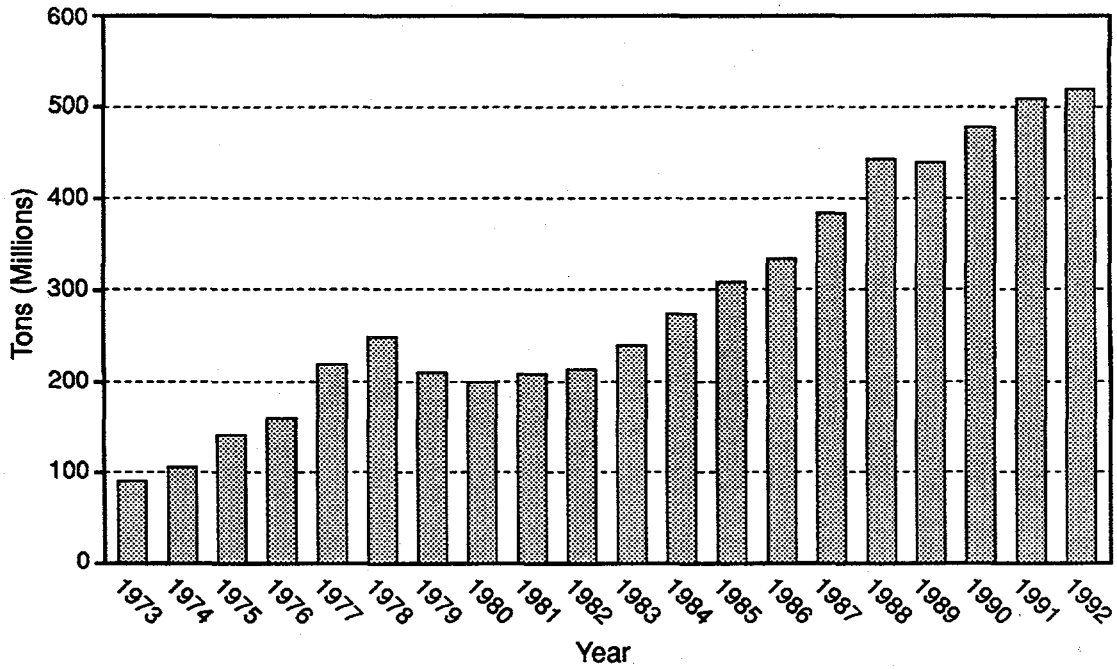
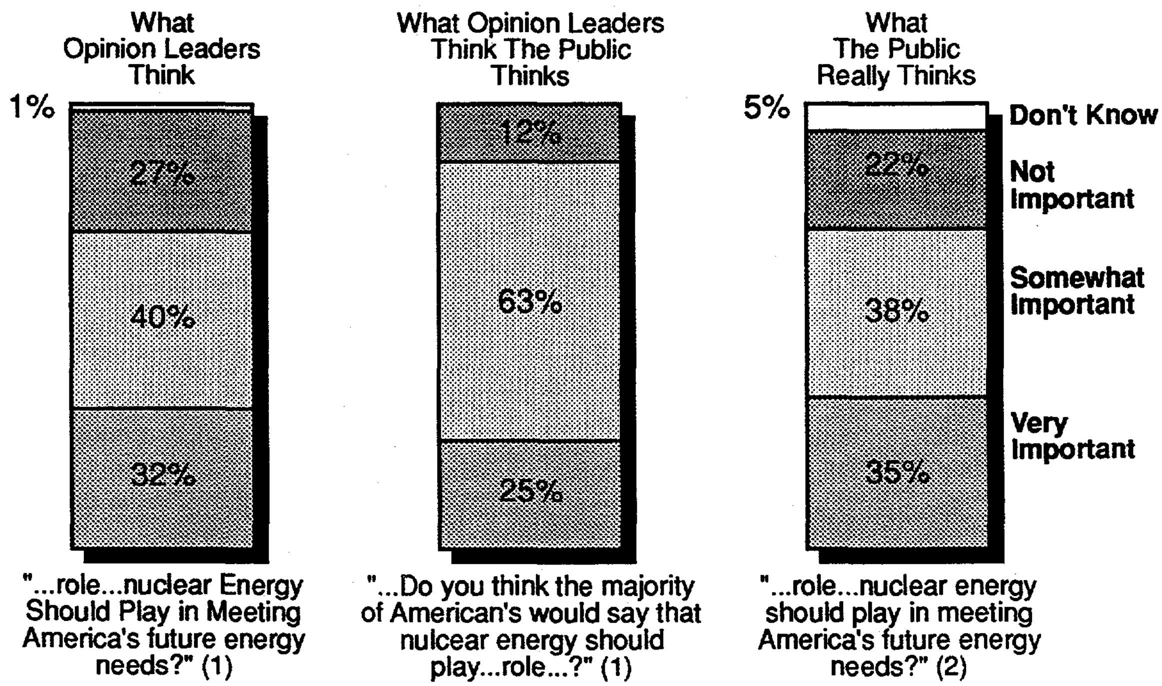


Figure D.11: Annual CO_2 Emission Displacements From U.S. Nuclear Plants (1973–1992).



Sources: (1) Cambridge Reports, March 1992
(2) Bruskin/Goldring, February 1992

Figure D.12: Opinion Leaders Underestimated Public Support For Nuclear Power.

SESSION FIVE

WHAT TO DO ABOUT NUCLEAR WEAPONS PROLIFERATION, AND DO NEW REACTOR TO CONSUME PLUTONIUM MAKE SENSE?

DISPOSITION OF PLUTONIUM FROM DISMANTLED NUCLEAR WARHEADS

Harold Feiveson

Princeton Univeristy

RESPONSE:

DISPOSITION OF WEAPONS PLUTONIUM FROM THE WARHEADS AND STOCKPILES OF THE U.S. AND FORMER USSR

Robert Budnitz

Future Resources Associates

INTRODUCTION

Session 5 – What to Do About Nuclear Weapons Proliferation, and Do New Reactors to Consume Plutonium Make Sense?

The problem of plutonium diversion and nuclear weapons proliferation has been present since the end of World War II. However, during the past five years it has become much more acute as would-be nuclear weapons states have become more capable and technically sophisticated—as was perhaps best exemplified during the disarmament of Iraq following the war in 1990. This situation has been exacerbated by the sudden increase in potential availability of weapons materials caused by the collapse of the former Soviet Union.

Important potential nuclear weapons states include Algeria, Argentina, Chile, Egypt, Indonesia, Iran, the Koreas, Libya, Pakistan, Saudi Arabia, South Africa, Syria and Taiwan. Most other states, primarily developing countries, currently lack the capability to acquire nuclear weapons. Notably, several states—including Canada, Switzerland, Austria, Australia have long had the capability to acquire nuclear weapons, and have shown no interest in doing so. Thus, whether a state is interested in becoming nuclear-armed must depend upon more than mere technological capability.

The question of how to deter nuclear weapons proliferation involves national motivations, detection of illicit nuclear material movements and safeguarding potential weapons materials. The last topic is the focus of this session of the Conference. This is because such materials have recently become much more available than previously, and because future reactors are being suggested as a means of making them difficult to transport and ultimately as a means of consuming them. The latter proposals can have serious implications concerning policies of separating the peaceful and military forms of nuclear energy, and the justifications for developing new types of reactors.

Of greater importance, however, is the potential that diverted materials might actually be used in nuclear weapons. The worst case is that such weapons might actually be used, but even their existence—or belief in their existence—could profoundly change international political power relationships. The potential for tragedy is much greater than the hope for a happy future.

This assessment of the future odds of a nuclear war rests upon recognition that the time scales required for any technical fix to the problem of weapons materials becoming available are all too long to justify optimism that human safeguards in all of the countries having such materials (including Russia and Ukraine) will reach the level of perfection necessary to prevent creation of even one weapon. For these reasons a session was included within the Conference devoted to restricting the diversion of weapons materials, and the roles which future reactors might play in accomplishing this.

DISPOSITION OF PLUTONIUM FROM DISMANTLED NUCLEAR WARHEADS

Harold Feiveson

Over the next decade or so, the U.S. and Russia could dismantle as many as 45,000 nuclear warheads, releasing potentially 150-200 tonnes of weapon-grade plutonium. In this period, Russia (where the safety and security of the plutonium is of most concern) will have to deal with 100-120 tonnes of recovered weapon-grade plutonium. It will also have to deal with an additional 50 tonnes of separated civil, reactor-grade plutonium being produced at its Chelyabinsk site.

REACTOR-GRADE VS WEAPON-GRADE PLUTONIUM

In this connection, it is important to insist that reactor-grade plutonium must be protected as securely as weapon-grade. This has been well established in a recent article by J. Carson Mark who for many years was director of the Theoretical Division of Los Alamos National Laboratory.[17] While weapons designers would prefer weapon-grade plutonium (consisting mainly of plutonium-239), reactor-grade plutonium could be used in crude designs by renegade countries and groups to produce nuclear explosives with a yield of at least one kiloton TNT equivalent; and it could be used by countries with sophisticated weapons programs to produce weapons that could reliably achieve yields of several tens of kilotons.

This is not to say that conversion of weapon-grade plutonium to reactor grade would not be useful. It would be.

DISPOSITION OPTIONS

For several years, the plutonium recovered from weapons will be stored at the dismantlement sites in the U.S. and Russia, probably in the "pits" of the disassembled warheads or in metal ingots. A new storage facility is being constructed in Russia, with the support of the U.S., but it will not be ready for about four years.

The principal long-term choices for disposition of separated plutonium divide roughly into three categories:[18]

- vitrify the plutonium in borosilicate (or other) glass along with high-level radioactive waste (HLW), which exists at plutonium-production sites in the U.S. and Russia, and then send the plutonium-bearing glass to a geological repository;
- irradiate the plutonium in reactors (either current LWRs or advance reactors);
- store the plutonium in some fashion until it becomes commercially usable in civil breeder or other nuclear reactors.

These options have been under study by the Committee on International Security and Arms Control of the National Academy of Sciences; and they will also be reviewed by the Clinton

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17 J. Carson Mark, "Reactor-grade Plutonium's Explosive Properties", *Science & Global Security*, Vol. 4, No. 1, 1993. In summary of Mark's arguments, the explosive yield of a fission weapon using reactor-grade plutonium in relatively crude designs would be uncertain because of the possibility of "predetonation" (where the chain reaction is initiated before the fissile assembly reaches its optimum state). Under such circumstances, the yield would not reach its maximum level. But even a "fizzle yield" (where the chain reaction is initiated at the worst possible time) would be on the order of 1 kiloton.

18 More exotic options such as sending the plutonium to the sun or dispersing the plutonium in the oceans do not appear today as realistic.

Administration, which stated last month that it will initiate a comprehensive review of long-term options for plutonium disposal.[19]

In the following, I address briefly the three principal options. Whichever option is chosen, it would valuable to put the weapons plutonium under international safeguards as expeditiously as possible. The U.S. has already stated that it would "submit U.S. fissile material no longer needed for deterrence to inspection by the International Atomic Energy Agency."

VITRIFICATION OF THE PLUTONIUM

Various vitrification strategies have been elaborated by a technical working group (Plutonium Vitrification Task Group) at the Savannah River Site.[20] In one of the central options studied by the group, the plutonium metal would be converted to oxide; the oxide would be incorporated into a glass powder in a small melter in a glovebox facility; the powder would be mixed with HLW; the mixture would be fed to a larger melter to produce pu-glass-HLW two-tonne logs; the logs would be stored on-site for some period; and finally the logs would be sent to a geological repository. All these steps could be done at the Savannah River site in the U.S.; in principle, they could also be done in Russia.

There are a number of potential advantages to plutonium vitrification: plutonium handling could be kept to a minimum, restricted to a few sites, and probably closely monitored and safeguarded; the plutonium could be processed at little incremental cost given that the glass would anyhow be made to incorporate the HLW (Savannah River estimates an incremental cost of about $1 billion to dispose of 50 tonnes of plutonium at the Savannah River site); and the plutonium would be made relatively inaccessible in a matrix which could be disposed of to a geologic repository together with other radioactive wastes.

The principal technical stumbling block to a vitrification strategy appears to be that the boron in the glass could separate from the plutonium in a repository, giving rise to criticality events, a risk which could limit the permissible concentration of the plutonium in the glass.

The principal political stumbling block is that in Russia, where the diversion risks of weapons plutonium are the most acute, many scientists and policy-makers have a strong aversion to disposing of the plutonium without getting any energy value out of it.

REACTOR IRRADIATION

As an alternative to vitrification, the plutonium could be incorporated into a fuel and irradiated in reactors—either current generation light water reactors (LWRs) or advanced reactors. After irradiation, the plutonium left in the spent fuel discharged from the reactors could be left there, or the plutonium could be repeatedly separated and recycled through the reactors until it is virtually consumed.

Conversion into Spent Fuel

There is no question that irradiating plutonium in LWRs could effectively convert the plutonium to a more proliferation-resistant form. It would reduce the amount of plutonium in the fuel by about 40% and mix the plutonium with intensely radioactive fission products in the spent fuel. Irradiation in LWRs will also convert weapon-grade plutonium to reactor-grade.

However, despite the potential of commercial LWRs to absorb weapons plutonium, there are a multitude of practical constraints which will severely limit the rate this can be done. In

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19 "Nonproliferation and Export Control Policy," White House Fact Sheet, Septmber 27, 1993, Washington, D.C. See also Frans Berkhout, et al., "Disposition of Separated Plutonium," in *Science & Gobal Security*, Vol. 3, Nos. 3/4, 1993; Frank von Hippel, et al., "Eliminating Nuclear Warheads," *Scientific American*, August 1993.

20 J.M. McKibben, et al., "Vitrification of Excess Plutonium," Westinghouse Savannah River Company, WSRC-RP-93-755, May 1993.

unmodified LWRs, MOX use is generally restricted to one-third of a reactor core because of the different nuclear properties of plutonium compared with U-235. Consequently, a 1000 MW electric LWR could process only about 0.3 tonnes per year. Russia has seven such reactors operating, with another nearly complete, and so could irradiate about 2.5 tonnes of plutonium per year. At this rate, it would take 40 years to irradiate 100 tonnes.

The use of plutonium on this scale and over such a long period raises troubling economic and security issues. No economic case can currently be made for using MOX fuel. Even if the weapons plutonium is considered free, the price of MOX fuel is significantly higher than the price of LEU fuel at today's uranium and enrichment prices.[21] More importantly, plutonium recycling on a large scale will involve a great increase in safeguards and physical security requirements.

Security risks could be reduced by building LWRs designed to accept full cores of mixed-oxide fuel at a few highly-secured sites. By tripling the amount of plutonium loaded at each reactor, the number of reactor years required to process plutonium surpluses falls correspondingly. However, safeguards and security requirements are only reduced in the least sensitive of the fuel cycle stages—the reactor. Plutonium fuel fabrication and fuel transport would still continue at the same rate, albeit dedicated to fewer sites.

Aside from LWRs, other candidate reactors for dedicated plutonium irradiation include the liquid metal fast-neutron reactor, such as the Integral Fast Reactor (IFR), and the high-temperature gas-cooled reactor. Fast-neutron reactors operating on a once-through fuel cycle could process even larger amounts of plutonium than LWRs because the percentage of fissile plutonium in fast reactor fuel is about four times higher for the same burnup.

Advanced Reactors/Complete Destruction of Plutonium

Both the IFR and the gas-cooled reactor have the potential to destroy most of the plutonium processed—the IFR by repeated recycling and the gas-cooled reactor by virtue of a very high fuel burn-up. But complete destruction of the plutonium does not seem a very compelling goal for two principal reasons:

1) It is pointless to expend great resources to destroy a large fraction of the weapons plutonium in the absence of plans to treat similarly the much larger amounts of plutonium contained in unreprocessed civil spent fuel. By the year 2000, over one thousand tonnes of plutonium will have accumulated in such fuel, with an additional 200 tonnes of separated plutonium in surplus stockpile.

   If the goal of plutonium destruction was extended to civil plutonium, it would entail reprocessing all the spent fuel in the U.S., Russia, and elsewhere and the construction of a fleet of IFRs or other reactors to burn the newly separated plutonium. This looks impractical.

2) In the case of the IFR or other fast reactors, the extensive separation and recycling required to burn up all the weapons plutonium raise serious proliferation concerns (which, of course, would be multiplied if the goal was to separate and burn up all civil plutonium as well).

   With a nominal range of net plutonium reduction per cycle for the IFR between 20 and 40%, scores of cycles would be necessary to effect essentially complete destruction of the original plutonium, spanning a period of perhaps a century or more. The destruction of plutonium which would otherwise be disposed of in spent fuel would reduce the amount of plutonium underground in geological repositories. This would reduce the risk that the plutonium could be "mined" after a period of a few hundred years when most of the radioactive fission products in the spent fuel had decayed. But this risk must be compared to the proliferation risks of continued plutonium recycling above-ground over a hundred years.

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21 MOX fabrication costs in Europe today are about $1300-1600 per kilogram heavy metal and the cost of an equivalent amount of low-enriched uranium fuel is about $1000 per kilogram. At a plutonium concentration in the MOX fuel of 5%, the use of plutonium in LWRs would require a subsidy of approximately $6000 to $12000 per kilogram.

The IFR could be configured so that plutonium separated by pyroprocessing would, in normal operation, always be contaminated with other actinides and with rare earths. This could significantly diminish the attractiveness of the plutonium for theft and weapons use. But, if the IFR became widespread, countries could operate the reactor is an "off-normal" way to produce uncontaminated plutonium; or the IFR product stream could be decontaminated by aqueous processes. Neither the IFR or any other civilian nuclear technology, with can be kept restricted only to "safe" countries while denied to much or all of the developing world.

In any case, both the liquid metal and gas-cooled reactors require considerable development and demonstration before they could be considered ready for full-scale implementation. (This is even more true of another proposed route to plutonium elimination: irradiation by neutrons produced in targets bombarded by protons accelerated to high energies.) The cost would be several billion dollars and at least a decade of delay. And once the technology had been demonstrated, there would still be costly production facilities to build.

STORAGE

A third option to dispose of the weapons plutonium would be to store the plutonium in forms of high diversion-resistance but such that the plutonium could eventually be retrieved. The conflicting goals of any storage option, as it applied to Russia, would be:

1. To make the plutonium inaccessible to terrorists, rogue military commanders, and renegade countries;
2. To make the extraction of plutonium for weapons at least time-consuming for Russia if it wished to reapproriate the plutonium for weapons;
3. Nevertheless, to make possible extraction of the plutonium for civil power in the future if this seemed economically sensible.

This last goal is to meet the concerns of Russians who do not want to dispose of the weapons plutonium irreversibly, without getting any energy value out of it.

Several possibilities have been examined including, for example, the following:

- To incorporate the plutonium in large glass canisters or logs, but without the HLW; this option has been studied by the Savannah River group and would follow the flowsheet for the incorporation of plutonium with the HLW, but without the mixing with the HLW;
- To mix the plutonium with "chemical spoilers," which would make the later chemical separation of the plutonium difficult, and then to imbed the mixture in massive, discrete structures such as heavy logs of glass or heavy units of other material. This option has been looked at by Prof. Scott Simonson at MIT. Candidate spoilers which have been suggested include elements in the lanthanide and actinide series.

In both cases, without the complication of radioactive wastes which require any processing to be done remotely behind massive shielding, the incorporation of the plutonium could probably be implemented more rapidly, both in the U.S. and Russia, than the vitrification-HLW and reactor options;

The massive, discrete structures could be stored retrievably in safeguarded stores. The size of the logs/blocks would deter theft and allow effective physical security of the store by the state guarding the store. The countability of the logs/blocks and the absence of fission products would promote effective measurement of the plutonium in the store and effective containment and surveillance by international safeguard authorities. The glass matrix or the chemical spoilers would at least delay renegade states or terrorist groups from extracting the plutonium, even if they obtained a log. The logs/blocks would be in a form that could eventually be sent to a geological repository if it were finally decided that was the best route.

In the meantime, these storage schemes would not prevent the extraction of the plutonium by a determined and sophisticated country. Russia probably would be able to reappropiate the plutonium for weapons relatively straightforwardly. This is a proliferation drawback. However, the advantages of getting Russian weapons plutonium into more diversion-resistant forms relatively quickly might (and, in my view, do) outweigh the long-term risk that Russia might some day want to use the plutonium again for weapons.

In general, in contemplating what to do with U.S and especially with Russian plutonium, I believe that we should give much more weight to the risks of theft and blackmarket transactions than to the risks of breakout by Russia and a "reconstitution" of a nuclear arsenal of tens of thousands of nuclear weapons. These latter risks seem very low; and if they did emerge, would not give Russia any significant military advantage.

RESPONSE TO H.A. FEIVESON

DISPOSITION OF WEAPONS PLUTONIUM FROM THE WARHEADS AND STOCKPILES OF THE U.S. AND FORMER USSR

Robert Budnitz

This short paper will summarize and in some cases amplify the remarks made during my "Respondent" talk at the Second MIT International Conference. The principal paper on the subject of disposition of weapons plutonium, by Dr. H.A. Feiveson of Princeton University, contains all of the principal arguments, both technical and institutional. In this "Respondent" paper, I will attempt to outline the key issues and provide my own perspective as to the relative emphasis among them. The reader should refer to Feiveson's accompanying paper for specific technical details on the subjects that I will only touch upon briefly here.

OBJECTIVES OF DISPOSITION

I have identified two different policy objectives of a disposition campaign: one may desire either the total elimination of the weapons plutonium, or the modification of it to a form that is significantly less available for weapons-reuse than in its current form as mostly bomb-core metal, followed by ultimate disposal in a deep-geological repository. I will discuss these two objectives in turn.

An alternative is a policy decision not to undertake such a disposition campaign but to store the plutonium for ultimate use as start-up fuel for a breeder-reactor economy. I will not discuss here the considerations that would weigh in, one way or the other, in influencing a policy choice to store rather than to dispose. (This is not because I am not interested in the policy debate on this subject, but because it is not my topic here.)

TECHNICAL OPTIONS FOR DISPOSITION

There seem to be only three practical options for disposition. The plutonium can be either (i) fissioned in reactors, (ii) vitrified into a waste form suitable for deep-geological disposal, or (iii) disposed of directly in a deep geological borehole. Of these, the last has not been studied carefully, is widely thought to be unsuitable because demonstrating effective long-term containment of the plutonium is thought to be infeasible, and will therefore not be discussed further. I will concentrate only on the first two.

THE ELIMINATION OPTION

If the objective of a disposition campaign is total destruction (elimination) of the plutonium, then the only feasible option is fission in reactors, including reprocessing/recycle to capture the unfissioned plutonium that is always present in spent fuel, sending it back through the reactor(s) for another pass. However, because there is several times more plutonium in current worldwide power-reactor spent fuel than in the weapons stockpile, and because totally eliminating the weapons plutonium without dealing with the spent-fuel plutonium does not make sense, the elimination option must deal with the whole world's Pu inventory in one unified campaign. A worldwide commitment to the goal of elimination would be a prerequisite, and the campaign would require many hundreds of reactor years worldwide, many cycles of reprocessing and recycle, and very large costs over several decades. Today there is essentially no discussion worldwide about the desirability of such a total-elimination policy—indeed, it is clear that if such a policy were put forth by, say, the U.S., it would be totally rejected by most of the world's most important powers, including the Japanese, the French, the British, and the Russians.

I therefore conclude that even if one strongly seeks the long-term goal of plutonium elimination, there is essentially no prospect in today's world for achieving it soon. Today, total elimination seems to be more a utopian than a practical policy alternative. However, because all of the plutonium ever produced is still on the surface—that is, none of it has yet been disposed of in a deep geological repository—the policy option of ultimately eliminating all of it remains available for later consideration, say a decade or more hence. This would still be true in principle once some of the plutonium were to be disposed of in a deep repository (whether as a major component of spent fuel or in vitrified glass), but in practice it would be increasingly expensive and difficult.

This leaves us with the other possibility, which is a weapons-plutonium disposition campaign in which the objective is to modify it to a form that is significantly less available for weapons-reuse than in its current form as mostly bomb-core metal. Here the two practical options are vitrification and fissioning in a reactor. It is important to repeat that neither approach, if chosen, forecloses a later decision to eliminate the Pu completely by an extensive international elimination campaign.

THE MODIFICATION OPTIONS

I begin by observing again that the weapons plutonium, perhaps 200 metric tons in all worldwide, is smaller in total mass than the spent-fuel plutonium that today includes about 700 tons worldwide and is increasing by about 50 tons/year. This spent-fuel plutonium must be safeguarded against diversion in any event.[22]

It is a reasonable notion that the policy objective for any modification option should be making the weapons plutonium, currently mostly in the form of bomb-core metal, approximately as resistant to diversion as the larger spent-fuel stockpile. I will adopt that common-sense figure-of-merit here.

As mentioned, the two practical alternatives are fissioning in reactors and vitrification. I will briefly discuss here my conclusions as to the attractive features and the limitations or liabilities of each of these.

- First, both vitrification and reactor-fissioning can successfully achieve the policy objective of making the weapons plutonium approximately as resistant to diversion as the larger spent-fuel stockpile. When fissioned in any of the feasible reactor options, the residual weapons-Pu ends up in spent fuel that, for all intents and purposes, is just as difficult to turn back into a weapon as the larger body of existing spent fuel. For the vitrification option, it is necessary to adopt an approach of vitrifying with a significant amount of highly-radioactive material, such as would be the case in the only near-term US vitrification option, which would put the weapons-Pu into the input stream to the Savannah River Site's Defense Waste Processing Facility (DWPF). The DWPF plans to turn out two-ton glass logs laden with high-level radioactive defense waste that can only be handled remotely; the weapons Pu would be a minor additional constituent of those glass logs.

- Second, while various advanced-reactor concepts have been proposed to accomplish the weapons-Pu disposition task, there does not seem to be any strong advantage to them

22 Here I must note in passing that, contrary to some widely-held opinions in the technical community, there is not much distinction in practice between so-called "weapons-grade" plutonium (containing less than about 6% of the undesirable isotope Pu-240) and "reactor-grade" plutonium with about 20% Pu-240. It is now publicly known that a highly destructive bomb can be made from either material. For the bomb-designing cognoscenti, the weapons-grade material is highly preferable in important technical aspects. However, a diverter, especially a sub-national group or a small non-weapons-state country, can make do quite well with reactor-grade plutonium.

(compared to using today's LWRs or perhaps evolutionary LWR designs similar to today's LWRs) that would outweigh the delay implicit in the fact that these advanced designs do not yet exist and will not exist for many years to come. To me, what this means in practice is that, if any of the advanced designs are to be built based on their other merits, it would be sensible to consider a weapons-Pu campaign as part of their overall deployment, but in my view a decision to deploy one of these advanced designs should not be taken with weapons-Pu disposition as an important rationale. Therefore, for the remainder of this presentation I will concentrate on using existing LWRs or evolutionary advanced LWRs as the fission option.

- Recent studies by DOE show that the costs of both the vitrification approach and the LWR-based disposition approach are similar and quite modest in the overall scheme of things—ranging from about $1 to 5 billion depending on the assumptions as to how quickly and in which facilities the disposition campaign might occur.[23] In the US, the vitrification approach would be less expensive than the reactor-fission approach if one could use the existing DWPF facility and could piggyback onto the planned high-level-waste-vitrification campaign by simply adding the plutonium to the input stream. Some of the reactor concepts may appear to be less expensive if credit is taken for the electricity generated, but in fact if the electricity would be generated in the same facility with normal (uranium-235) fuel then this benefit is mostly illusory. One principal and unavoidable cost associated with any of the reactor options is constructing a plutonium-fuel-fabrication facility which represents an investment in the billion-dollar range.
- Using a full-MOX-core approach with PWRs means that 200 metric tons of weapons-Pu could be irradiated into spent fuel in about 240 reactor-years (for a nominal 1000 MWe reactor); for a one-third-MOX-core approach the campaign would take about three times as many reactor years. For BWRs the numbers are similar.
- A vitrification campaign could not begin for 8-10 years even if a major push were made because various technical issues and licensing issues must be resolved (see below), including a safety-certification or licensing process that could be difficult. A campaign to vitrify 50 tons of weapons-Pu at the DWPF would take perhaps 8-10 years, and disposing of 200 tons would either take correspondingly longer in the DWPF or would require construction of additional capacity.
- A reactor-fission campaign in the U.S. also could not begin for about 8-10 years even if a major push were made, because a fuel-fabrication facility must be constructed and various safety and other approvals obtained, both the that facility and for the reactors themselves. The duration of the campaign depends on how many reactors could be dedicated to this purpose—see my comment above for the number of reactor-years required.
- There seem to be no technical issues standing in the way of fabricating either full-MOX or one-third-MOX fuel and using that fuel in LWRs—this technology has already been successfully demonstrated in Europe.
- There are a few important technical issues that must be resolved before we will have high confidence that vitrifying weapons-plutonium is feasible. Among the most important issues are designing the vitrification equipment to preclude criticality, and assuring that the resulting Pu-laden glass logs can be sent to the Yucca Mountain repository (not yet formally licensed but in the throes of a long and complicated certification process as of now) without criticality concerns there many millennia hence. These issues seem to be resolvable, but more technical work is necessary before we will know for sure.

23 The word "modest" attached to costs in the few-billion-dollar range may seem strange, but it should be recalled that the costs of maintaining the stockpile safely over many years without disposition are in the same range, without any of the benefits of disposition.

- There are enough reactors in both the US and Russia to accomplish a reactor campaign successfully if a one-third-MOX-core approach is taken. In both countries it would be necessary to modify existing reactors to accommodate full-MOX cores so as to expedite the campaign or to carry it out in fewer reactors. These modifications are not overly expensive but would require several-month downtimes to accomplish the backfits to the control-rod systems. (All existing LWRs can accommodate one-third-MOX cores today; the U.S. has about 110 commercial reactors but only three can accommodate full-MOX cores today; Russia has none that can take full-MOX cores today.)
- While vitrification technology exists in Russia, their approach has concentrated on a phosphate type of glass that is judged to be technically unsuitable for plutonium disposition, as compared to the borosilicate glass that the U.S. facility (the DWPF) will use and that is fully compatible. The Russians have no experience with borosilicate-glass vitrification, and it is an open question as to whether that technology could be adopted there without difficulty.
- The occupational-risk, environmental-emissions, and accident-risk aspects of any of the schemes under current consideration appear to be well within modern practice and should not result in any unusual risks or impacts.
- When either a vitrification campaign or an LWR-based fission campaign is completed, the resulting end products (glass logs or spent fuel) must still be handled safely and ultimately disposed of safely in a deep geological repository. While issues remain as to how this ultimate disposition will occur, I conclude that the safety and security aspects of the two schemes are similar enough that differences among them should not drive this decision.

SUMMARY

I conclude from the above that either vitrification or LWR-based fissioning could be an effective way to modify the weapons-Pu to meet the policy objective of making it approximately as resistant to diversion as the larger spent-fuel stockpile that already exists. The costs are similar; the schedules—time before a campaign could start and duration of a campaign—are similar; the safety and environmental risks and impacts are similar and modest; and the endpoint products (spent fuel or glass logs) are similar in their crucial attributes.

Therefore in my opinion the decision about what to do ought to be made on another basis, presumably a political basis involving the following considerations:

- Whether vitrification, which "throws away" the energy content in the plutonium, will be an acceptable approach—this issue has been especially important to some of the Russians who have adamantly opposed "throwing away" the plutonium's energy, even though the actual cost of both disposition schemes is quite similar. (Of course, if the alternative is saving the Pu to start up a breeder-reactor economy, then "throwing it away" does indeed constitute a penalty.)
- Whether starting a disposition campaign "soon" (within a decade) is judged to be important enough that a decision should be made primarily on that basis;
- Whether enough commercial power reactors, in both the U.S. and Russia, can be made available for the disposition mission. In the U.S. this is a matter of utility reluctance to "mix weapons and electricity"; of a U.S. government policy against the use plutonium fuels in general as part of a long-standing policy opposed to fuel-reprocessing and plutonium recycle; and of a possible problem with convincing the U.S. public to accept using commercial reactors in this way. (One way out of this latter dilemma would be for the U.S. government to purchase one or more existing commercial reactor units, including either units now operating or units that have already been shut down, will be shut down soon, or were never completed.)

- Whether the approach to be taken in the U.S. must be similar to that taken in Russia, or can be different;
- Whether the issue will ultimately be decided based mainly on the usual political issues that determine so much U.S. policy—issues such as government-created or government-supported jobs and their location in various congressional districts, porkbarrel issues, budgetary constraints, and the like.

In general, I conclude that I have a strong desire to get on with disposition of the weapons-Pu as urgently as can be accomplished, mainly as a sign to ourselves and the rest of the world that we are really serious about ultimate disarmament and about making the world more diversion-resistant.

Whichever scheme will work best to accomplish a speedy start along the disposition path seems best to me. I have not addressed the broad issue of whether saving the plutonium to start up a breeder-reactor economy is desirable because I see that as not closely related to the safeguards/security issue here that involves starting along the path toward better security/safeguards for the weapons-Pu, now mainly in the form of bomb-core Pu metal.

WHAT TO DO ABOUT NUCLEAR WEAPONS PROLIFERATION, AND DO NEW REACTOR TO CONSUME PLUTONIUM MAKE SENSE?

DISCUSSION

Academic Socio-Technological Scholar:

I have been deeply troubled by the linkage that seems to have been accepted in this country between nuclear weapons proliferation and the nuclear power industry. I do not in anyway want to be critical of the discussion that has gone on here, since today's discussions are entirely appropriate for a meeting like this.

However, I am troubled at how the meeting has focused on the proliferation problem. We have focused almost entirely on the possibility of dealing with it through policies of denial. This policy is to prevent people from getting access to plutonium or to highly enriched uranium through enrichment technology, to reprocessing technology or what have you. It seems to me that in the long run this is a losing game. It can be effective. I am sure it has been effective to some degree in slowing down the Pakistani effort to acquire nuclear weapons but it did not stop them.

So I think that we need some change in national policy in how to deal with this problem. Now, if we look at matters from a historical point of view, we find that there is an extraordinary range of ways that nations have gone about getting into the nuclear business. Take the two extreme examples of Israel and Canada. The Israelis have what I take to be a rather impressive weapons program. However, I am unaware of any serious interest in nuclear power. At the other extreme, the Canadians have an impressive nuclear power program, and I have seen no great interest in nuclear weapons.

There are other countries that fall between these two extremes. China for long time, at least, has focused entirely upon the weapons aspect of nuclear energy. Japan and Germany, which as far as I know are not yet advanced in the nuclear weapons business, both have impressive nuclear power programs. India falls somewhere in between. I can think of no country that started down both paths simultaneously, with the leadership of the program provided by people who represented both interests.

I ask why did Israel and China focus as they did on weapons, while Canada, France and Germany did not. The answer is obvious, I think, to everybody in this room. Israel and China had, very difficult security problems. Canada, Japan, and Germany, did not. This is more obvious, particularly in the case of the Germans, who felt secure enough to sign the North Atlantic treaty, and with the Japanese where there was the U.S.-backed security guarantee in effect.

It seems to me that the nuclear weapons technology is becoming increasingly more accessible. That is inevitable. I remember talking with an Indian scientist who was doing nuclear research, who observed that he had nothing to gain from getting nuclear weapons technology. I think that he was right. It is a 1950's technology that any country with any reasonable industrial capacity can obtain. The safety standards and environmental standards of nuclear power are nothing like we demand of similar programs. The costs are at least an order of magnitude greater.

I grant that countries like Libya or Chad might have some difficulty for some years, but a country with a modest industrial infrastructure could obtain weapons. So the best that we can do through polices of nuclear denial is to perhaps to delay weapons acquisition, or hopefully prevent it. I suspect that we can work calmly for quite a few years to prevent some unstable leaders from getting the capability to make their own weapons.

With countries which we need to worry about, weapons denial is probably a losing game. However, I do not see any possibility of our going down the other path, that of providing security guarantees as we have in the past. We guaranteed the security of Saudi Arabia, of Japan, of all the countries of NATO. We are getting pretty close, not in terms of a treaty obligation, but in terms of national sentiment and by our actions, to guaranteeing the security of Israel. But, even that did not prove sufficient to deter them from having their own weapons program.

Now, concerning the current U.S. administration, in view of its actions during the last few months; it seems to me incredible that we are going to go very far down the path of providing security guarantees for many countries. Nobody else is going to go very far down that path either. They cannot do so without U.S. backing. I do not believe it is in the cards that this country will guarantee the security of North Korea; nor, for example, will we be prepared to guarantee the security of Ukraine or Pakistan. That being the case, the dilemma is what our proliferation policy ought to be. I can imagine two extreme versions. One is to throw up our hands and do nothing. This would recognize the fact that the alternative forms of plutonium sequestering, or of burning, so that others cannot get their hands on it probably will not work. Maybe doing those things is not worthwhile. It can be argued that countries about which we are concerned will acquire nuclear weapons unless their security concerns are dealt with. That is an extreme view, and I do not subscribe to it. I put it on the table to make a point.

The other extreme view is that it is quite clear that we are not going to do anything serious about the problems of proliferation. Even though we are going to be unable to deny weapons materials, we should do all that we can to ensure a consistent policy. One can argue that we should do this even at a highly considerable cost. I think that is also a rather extreme view.

Something in between is probably indicated. My own sense is that it is worth doing something to try to reduce the likelihood that plutonium and highly enriched uranium will be diverted to make weapons.

The programs of the major countries to reduce the likelihood that enrichment technology, reprocessing technology, or production reactor technology will be exported all over the world are probably worthwhile. But we ought not to do so in the misguided belief that this is going to solve the proliferation problem. It may help a little bit more in deferral than it will in prevention. All that I am suggesting is that for all of the discussion about dealing with plutonium, or dealing with the technology that is used throughout in the power industry; it is well to understand that this does not constitute dealing with the proliferation problem in a very effective way.

U.S. Energy Researcher:

I would like to second most of the views just expressed. I also wish to make three main points. The first point is that, although the proliferation concern was recognized as a potential problem from the beginning of the civil nuclear program, and during forty years of civilian power development history, there has not been a single case where a nation has used the civilian nuclear power plant or civilian reprocessing capability as a pathway to acquire weapons material. This is very significant. The reason that this did not happen is that using a civilian nuclear power program as a pathway to weapons will compromise a nation's energy situation. A nuclear power economy is very expensive enterprise, which is very important to national security. Also, there are many alternative ways to acquire nuclear weapons materials clandestinely.

That the civilian energy program has not yet been used to acquire weapons does not mean that because it has not happened in the past we do not have to worry about this misuse of commercial nuclear power in the future. We have to worry about the issue.

That leads to my second main point, which is that the proliferation concern has to be addressed in a complete context. We cannot address it as a technical issue on an absolute basis focusing upon where in the fuel cycle plutonium is found. It is a very complex issue, which we have to address in terms of international safeguards, which have worked with civilian nuclear power. However, this success depends upon the political stability of the world and international diplomacy. This is the reason for my first point; that civilian nuclear power has not been misused until now. The relevant institutional arrangements have worked, more or less.

So one has to look at this much bigger, more complicated issue; that of the nuclear power and the plutonium industry. Now I like to come my final main point: dealing with the sophisticated technology of IFR pyroprocessing. It has been suggested that once it is used it may encourage growth of the use of plutonium in the nuclear economy, in addition to contributions to waste and plutonium disposition.

Now, I would like to look at that technology and the issues associated with it. The proper frame for this technology at the earliest is the year 2010 or beyond, because that is about the earliest time that the IFR nuclear liquid metal reactor can become commercialized. In Prof. Golay's opening remark yesterday, he did not state a time frame for the LMR. He said that it is later in than 2020. I say that it cannot be any earlier than 2010. Now, what would the situation be in 2010. We will have about 2000 tons of plutonium contained in spent fuel from commercial reactor operation, even should we not add more nuclear generating capacity. We will also have several hundred tons of separated plutonium from commercial reprocessing in Europe and Japan. Overall, we will have roughly 200 tons of separated plutonium, all within that time frame.

I would like to mention the few technical aspects of IFR pyroprocessing. This electrorefining-based process is radically different from the conventional aqueous reprocessing in many ways. Most importantly this process does not involve separated plutonium. The process is simply incapable of producing pure plutonium, so that the product from the electrorefining is a mixture not only of plutonium, but of all other actinides like americium and curium, as well as uranium and rare-earth fission products. It is highly radioactive. Because of the presence of the mixture of uranium and actinides being treated this material cannot be used as weapons material directly. For this use it has to be processed further by aqueous processing.

Dr. Feiveson mentioned the potential of using blanket material from the IFR as being closer to a weapons material. As I discussed in yesterday morning's remark and also as Mr. Brolin indicated in last night's dinner speech, we are developing the IFR technology to use plutonium burner, not to be a breeder. So, there will need to be no blanket in the IFR for the first 50-70 years of deployment, depending on the rate of introduction of fast reactors. So, the blanket is not a factor. The charge that the IFR produces weapons material is irrelevant anyway because the plutonium produced is not made available for diversion. Any reactor can produce plutonium from its uranium, based upon the fuel radiation time. It can be done with any reactor other than the IFR, too.

As I said in my first point, the commercial reactor plants have not been used as the pathways to proliferation. So, I think that the weapons production issue is a red herring. There is a question as to whether this technology will be applied to treatment of spent fuel, thereby stimulating a plutonium economy, which would involve large scale plutonium shipments. This is the main issue that we are dealing with in developing the IFR for use beyond the year 2010. This process we are developing is not commercially justified, but is intended to be used immediately, meaning by 2010. It does not add any initial risk to the situation that may already exist as a consequence of whatever fuel processing you will already have performed. Rather, this use of the IFR could mean a positive step toward solving proliferation concerns. As I said in the second point, the proliferation issue is a more complex institutional issue, where technically the IFR option could provide some advantage because pyroprocessing does not separate out plutonium. If this technology can replace the, currently available, aqueous reprocessing, then we could eliminate separated plutonium from the commercial fuel cycle. And this would be a positive step forward.

Secondly, by consuming plutonium in the IFR, generating energy, we can in fact start the burning of plutonium, whether it is from spent fuel or separated plutonium. I think that this would be a positive step in the long term process of eliminating plutonium from the stored inventory. Also this could reduce incentives for developing countries to enter the plutonium economy, using reactors which involve separating plutonium. So, I think you will have a much better future at the long term.

These are the things which tie the IFR technology to reducing the proliferation risk and what to do with the weapons plutonium. Dr. Budnitz mentioned the intermediate plutonium sequestering option. The breeder option is not for the intermediate term. It is really a long term option. However, liquid metal reactors, because of their fast neutron energy spectrum, have a very large plutonium inventory requirement. Therefore, a very large amount of plutonium can be tied up immediately in reactor cores when they begin operating. This then makes it into spent fuel, which is indistinguishable from the conventional spent fuel. We are talking about an addition of 10 tons of initial plutonium for the active fuel inventory, and another 10 to 20 tons which can be put into the fuel complex for reloads over about a 5-6 year time period. Now, commercial LMR operation can occur by 2010, but we do not have to wait for commercial operation. Especially in Russia they have the VM-350 and the VM-600, which have been operating very successfully over the last few years. They have the three VM-800s of 800 MWe each, which have been under construction but which were suspended because of financial difficulties. These reactors can be used to tie up many tons of plutonium in the fast reactor fuel cycle. If we can have a diversion-resistant pyroprocessing technology being used with it, the liquid metal reactor can provide solutions for immediate development. So, I think that there are immediate solutions that the liquid metal reactor technology can provide in the near term as well as in the long term.

Dr. Robert Budnitz (Future Resources Associates):

As far as I am concerned the only proliferation threat that this weapons plutonium poses in Russia concerns the renegade colonels. It does not do anything about Pakistan acquiring nuclear weapons. It does not forbid the Israelis from nuclear war. It is not going to restrain the Russian government, who will always have at least 5000 weapons anyway.

It is the renegade colonels that I am worried about. A problem could involve a renegade colonel in Russia aiding the Pakistani army, or it could be somebody who takes a weapon and gives it to the Pakistanis. This is the sort of thing that is important, but by no means is the only thing that we must deal with. We need to focus on these problems. The IFR does not solve them. Unless you believe that you can store the plutonium securely while waiting for the breeder, than relying upon the IFR as a solution is not so terrific.

Dr. Harold Feiveson (Princeton University):

It has been said here that to encourage use of the Advance Liquid Metal Reactor (IFR) in the United States and industrialized countries would somehow help discourage other parts of the world from getting nuclear weapons technology. When we think in the long term about what kind of nuclear technologies would be acceptable, it is important not to imagine that some technologies, which are dangerous in a proliferation sense, could be kept out of the hands of countries that are less trustworthy than ourselves and our allies. This is not realistic.

If you think of a long term nuclear future, it has to be based on a nuclear technology in which there is comfort that it could be shared in a non-discriminatory way around the world. I cannot imagine that there will be a future of that sort. I think that puts into question any kind of serious long term future for nuclear power, particularly one on a scale that could address the greenhouse warming problem as Prof. Golay described.

Mr. Thomas Cochran (National Resources Defense Council):

I believe that there is more plutonium to be dealt with than suggested by Dr. Budnitz. Also, there is another issue that has not been raised in these discussions in terms of the objectives and how much plutonium it is viewed as a problem. I believe you need to ask what are the ramifications of these various themes for the disarmament process itself. If you leave large stocks of separated plutonium in storage, I personally believe you have locked yourself into the continued existence of very large inventories of weapons—either as active or inactive inventories in the United States, in Russia and in other countries. You might want to add to this list India, Pakistan, the United Kingdom and France.

I think that one has to ask what are the ramifications of these various policies, particularly those which take much longer to implement, concerning the disarmament process itself.

With regard to the Russian situation, there are a couple of things that are perhaps worth noting. One is that if Russia is separating about a ton of plutonium a year from civilian reactors, and another ton and a half a year of weapons grade plutonium from production reactors. Then consider, for example, the VVER plutonium destruction option, where there are seven reactors, with each core being one third MOX. You are talking about destroying two tons of plutonium a year, and also making two tons of plutonium a year. It requires a infinite time period to get rid of the plutonium.

My recollection is that India obtained the plutonium for its "peaceful" nuclear devices from its reprocessing plant. This plant is part of its civilian program. So we have in this example reprocessing plants, as part of the civilian program, being used for weapons purposes.

Now if the IFR objective is really to destroy plutonium, the first objective should be to turn off the operating reactors. The quickest way to reduce the plutonium inventory is to accelerate the turning off of the existing Light Water Reactors. We could cut down the IFR work load program by centuries if we would just stop nuclear power, so that we would have 200 tons rather than 2000 tons of plutonium to deal with.

Also I disagree about the IFR cost estimates. The important question is not that of how much plutonium can be handled per reactor-year, but it is how much plutonium that can be handled per dollar. I think that the IFR would come out as a real loser in this area.

Concerning the vitrification option, one of the problems which the Russians have is that 2/3 of their high-level waste is deep well-injected. So, they will argue that they do not have a lot of high-level waste and fission products. The only thing that they have is the ground and water that have been contaminated, because they just dump the waste into the ground. So, to find waste in Russia, I suppose that you just pump it out of the ground or contaminated lakes.

U.S. Nuclear Power Industry Professional:

I would like to elaborate on the characteristics of the helium-cooled reactor for its potential contribution to solving the plutonium problem, and secondly I would like to describe the agreement which General Atomics has with Minatom, the Russian Ministry of Atomic Energy, for developing a reactor burning plutonium. First, several people have noted the virtue of the gas reactor in once-through high fuel burn-up. In that reactor plutonium will have a very high destruction fraction. It is the destruction of the plutonium at about 90% that really puts the gas-cooled reactor in a different category in terms of weapons material consumption.

Also, I disagree with the schedule being quoted in connection with the IFR for building plutonium-burning reactors. For example, for whatever time it takes to put in some light water reactors into service, we will need about five years longer. This should not be a major consequence because no matter what you do for plutonium consumption, you also must have plutonium storage capability. So, those are virtues of the helium gas-cooled reactor.

Let me quickly describe the agreement that we have with MinAtom, and why the Russians have wanted to work with us. First of all it turns out that the Russians have been working on the helium gas-cooled reactor longer than we have. They started in 1947. General Atomics was founded in 1955-56, so the Russians have been working on it for a very long time. They have always admired the reactor's safety characteristics, and they liked the reactor's particle fuel. I think that is the number one reason because of which they are so interested in the gas-cooled reactor.

Number two is that they like the economics that the gas turbine version of the helium-cooled reactor gives, for it will get them to about 48% thermal efficiency. That is a level of efficiency like they have never seen before, and which we have never seen also. They have examined the feasibility of this system in some depth and they believe in it.

The third reason Russians want the gas-cooled reactor is that they want to put their physicists to work, so as to use their technical capabilities in peaceful ways. Many of the people who would be involved in this project in Russia are people who had been bomb makers. I think that this is a very good way to channel their technical expertise. The fourth reason the Russians would like to make a gas-cooled reactor is that they are interested in recovering the energy value of the fuel. They think it would be tragic to take that energy value and simply bury it, putting it out of use. The fifth reason is that it provides an opportunity to destroy the plutonium rather than having a big repository where people can extract whatever plutonium they desire, whether by the Russians or ourselves. So, I think they are interested, and we want to work with them.

The question of whether it is important to deal with weapons plutonium as opposed to the light water waste strikes me as one of the arguments that you come up when you talk about the drug and alcohol problem. It leads people to say that because more people are alcoholics you do not need to solve the drug problem. I think we can and should solve the weapons plutonium problem. Then, once we have solved that one, we can worry about solving the other, that of the reactor and its waste.

Public Policy Analyst:

I want to hearken back to one of the points which Mason Willrich made yesterday in describing his personal position on nuclear power. He said it has to be safe. It has to be economical, and the proliferation risks have to be managed effectively. Concerning proliferation, I thought that was a fine way to express it because the plutonium problem really does come down to one of manageability.

Whether the nuclear industry and the international agency (the International Atomic Energy Agency, IAEA) that the industry has created to help justify these activities are capable of managing the expected quantities of plutonium is the issue. I feel that production of large amounts of plutonium is almost inevitable. The nuclear power industry is ultimately responsible for the proliferation of weapons if it cannot manage its own plutonium waste product, in a way that minimizes risks and avoids catastrophic, unmanageable consequences. I do not today, and I did not 20 years ago, understand why plutonium was an essential fuel.

I agree with Dr. Budnitz's characterization that attitudes about plutonium and nuclear power basically come down to being like religion. The nuclear power establishment is an industry that is hooked on plutonium, and that will justify plutonium use one way or the other. Experts will cite special cases like Iraq, North Korea, India or Pakistan to show that the utilities are trying to exercise restraint. However, we must remember that the vast majority of the nations in this world are parties to the NPT (nuclear non-proliferation treaty) and have no interest whatever in plutonium.

The interest in plutonium is being driven by very special industrial and bureaucratic interests. We have to ask ourselves quite honestly whether worldwide or individual regional situations are currently such that things will become unmanageable in a very big way. I frankly do not feel that this industry is worthy of long term support if the best that they can do is to provide the mess that we now see in the weapons sites in the United States and the former Soviet Union. Also, it keeps finding ways to use plutonium as a fuel, even though it is widely recognized that the IAEA is incapable of effectively safeguarding against diversions from the commercial quantities of plutonium produced and handled in large facilities.

So, I must express a great deal of frustration with this discussion. I made some specific points yesterday about the IFR, quoting from the letter by John Ahearne to try to clarify the record. I think that actinide partitioning transmutation is not a rationale that justifies proceeding with this technology.

David Lillianthal said to me when I was first getting into this business that if you assume proliferation to be inevitable, of course, it will be. I think those are some of the wisest words ever spoken. I would hearken back that Florence Nightingale's position was that hospitals at the very least should not spread disease. I would also argue that the nuclear industry, at the very least, should not spread weapons-usable material into world commerce. These are basics.

In Clinton administration circles I am regarded as a fundamentalist; indeed a radical fundamentalist. But, when I turn to them, and ask for the kind of assurances that Mason Willrich has said have to be underpinnings of one's support for nuclear power, and I ask whether the proliferation risks manageable. I do not get any direct answers on that question. I would say that less is better than more, later is better than sooner. I agree that we should defer these problems to the fullest extent possible but I also think that we should start looking now to build a non-proliferation regime, based upon the premise that weapons-usable materials are illegitimate. You could build a verification regime to provide a high degree of assurance of proper access to these materials. That might work, but the regime being put forward now is unworkable and unmanageable. Also, it is going to cost a lot of money, and may just bring a lot of grief upon the world.

U.S. Government Employee:

I just want to report to all of you that, as part of the (national) administration, we have been working hard on this issue. Even before the President's statement of a few weeks ago there have been many discussions among the interagency task forces working on the issue of plutonium disposition. In terms of what we have been talking about this morning, I think it is important to think about three main points.

Point number one is that we do not yet have a place to put nuclear waste. We have a place which we are studying at Yucca Mountain, but we do not have closure of the fuel cycle. That fact sometimes gives us a little bit of a chill when we think about plutonium as a storage or long term disposal option. Even as we speak today we do not really have a good firm answer to when, and maybe where, we are going to dispose of commercial spent fuel.

Point number two: Anything that involves increasing the burden at the Savannah River reservation really increases the burdens on the U.S. government from the perspective of costs and environmental restoration and waste management. So if we are going to accept other people's waste it is going to add to our own overburdened Environmental Management (EM) budget. A deal to accept additional wastes is maybe cheap, relatively speaking, but when you are adding work to a program that is already reaching the ceiling when it comes to cost, it may be too much.

The third point concerns highly enriched uranium (HEU). Both it and plutonium impose non-proliferation control-related costs which no one had anticipated. It had always been assumed that HEU would have a market value and plutonium would not. This has turned out to be wrong.

When I go back to the previous speakers and listen very carefully to their discussions It seemed to me that they talked about from specific areas that need to be considered or about criteria. One was United States public acceptance which includes utility public acceptance. The second was Russian acceptance of whatever plutonium disposal option was available. The third was that of trying to maximize proliferation considerations or non-proliferation considerations. A fourth was technological considerations including economics.

I will add to this list a fifth consideration which is the U.S. budgetary deficit. Because I work with it everyday, I find that it determines what is possible. So, I will add that fifth issue as an important ingredient to anybody's analysis.

Dr. Budnitz:

As a parting note, I just want to remind you of line from *As You Like It*, "Sweet are the uses of adversity."

Prof. Golay:

Do you wish to say more?

Dr. Budnitz:

No, that is enough.

SESSION SIX

WHAT WILL HAPPEN TO OUR NUCLEAR WASTES?

Thomas Isaacs

Lawrence Livermore National Laboratory

RESPONSE:

Susan Wiltshire

JK Associates

INTRODUCTION

Session 6 – What Will Happen to Our Nuclear Wastes?

Nuclear wastes of all sorts are objectionable to many people. The differing reactions of laymen and technologists to this topic excellently illustrate C P Snow's concept of the existence of the two opposed cultures of the humanities and science. Among laymen the creation of nuclear wastes of a substance which can be lethal for millennia is frightening and unacceptable. This alarm is amplified by the evident impossibility of guaranteeing that none of these wastes will enter the biosphere in the future. It is further argued that the benefits of the activities which produce the wastes will accrue only to current generations (others note that future generations typically benefit from increases in the economic surplus provided by those of the past), while the burdens of the wastes will be borne only by those living in the future.

Among technologists the same reactions are often viewed as the results of feeble thinking. They note that existing and expected wastes currently threaten no one, and that technological concepts for treatment of the wastes offer reasonable promise of isolating them from human contact. Such mutual incomprehension between these two groups can make communication difficult. This fact is reflected in the intransigence of the current impasse over how to dispose of nuclear wastes.

The elements of fear of nuclear wastes affect many people. In addition, at potential waste repository sites, whose residents would be most affected should the wastes reenter the biosphere, factors of distrust of civil authorities has been important. There have been concerns that once in place, the wastes would not be treated with the care needed to protect the neighboring settlements, even through the expected risks of the wastes may be low. In the case of temporary storage proposals distrust that they might become effectively permanent facilities has also motivated distrust. The absence of significant benefits associated with receiving the wastes has also been noted as a factor which might explain some of the reluctance of virtually every potential host to accept either high or low-level nuclear wastes. Conceivably a system to reward such hosts more generously would break this impasse. It is notable that this impasse exists in virtually every country using nuclear power.

The result of distrust over nuclear wastes and the inability to site nuclear waste facilities has led to the demand that further use of nuclear power be halted until this problem is solved—whatever that may mean. Because the public controversy over nuclear wastes is having such a strong effect upon any potential expansion of nuclear power a session in the Conference was included. It has been organized to focus upon the reasons for the nuclear waste siting impasse and its consequences.

WHAT WILL HAPPEN TO OUR NUCLEAR WASTE?

Thomas Isaacs

Let me begin by answering the question which titles this session. What will happen to our nuclear waste—specifically the nation's high-level radioactive waste? I do not know, and neither, I believe, does anyone else. In the United States the program has changed direction and priorities on many occasions, often with unexpected consequences. My contention, however, is that this quite predictable, is consistent with the way contentious issues are often handled in this country, and while frustrating, is not entirely bad.

In this paper I will provide a brief, admittedly parochial view of where we have been, where we find ourselves today, and some possible futures, including a view of how we just might get there from here.

WHERE WE HAVE BEEN

In analyzing high-level radioactive waste management, it perhaps more important than with other nuclear projects to begin by understanding how we got to where we are today. The past can conveniently be looked at in three distinct periods: the period prior to the Nuclear Waste Policy Act of 1982 (NWPA), the period between the NWPA and the Amendment to that act in 1987 (NWPAA), and the period since the passage of the NWPAA.

1957–1982

From the advent of the nuclear era, it was always understood that eventually we would have to provide a solution for the disposal of the high-level radioactive wastes that were being created first from national defense activities and later from nuclear power plants producing electricity. It was also clear that these wastes would be intensely radioactive and therefore hazardous for extremely long times—essentially requiring permanent isolation from what is often called "the accessible environment." As early as 1957, the National Academy of Sciences recommended that the preferred method of permanent disposal would be in a stable geological formation (they suggested salt deposits) deep within the earth. Remarkably, more than thirty years later, this remains the preferred choice of all countries actively pursuing a permanent solution.

There was low priority assigned to providing such a solution during the early years. Attention was on the production of nuclear weapons and other nuclear related defense activities, with the waste often stored as what now seems to be little more than an afterthought to be dealt with later. And there seemed to be no compelling need to provide for timely disposal concerning the spent fuel elements from nuclear reactors, which were stored in pools of water at the reactor sites. Since it was expected that at some point these fuel elements would be reprocessed to regain the unused uranium and plutonium, only after the residual waste had been vitrified would there be a need for a final repository. So during this early period, while waste disposal activities continued, there was little sense of urgency.

This reluctance to move forward was exacerbated by a polarization that resulted in criticism and intense opposition each time the executive branch attempted to implement a solution. On one side were those who felt that this generation had an obligation to provide a timely and adequate, permanent solution to the disposal issue; that it was an unacceptable legacy to leave to future generations the wastes that we had created as a result of our appetite for electricity. Thus on several occasions, the government attempted to identify candidate sites for disposal only to run into intense political opposition, made worse by a lack of understanding as to just how deeply people and politicians resented being selected for consideration. Compounding the difficulties, the technical dimensions of the siting issue were also often oversimplified, most noticeably in the attempt to consider siting the repository near Lyons, Kansas, in a location that was to prove to be unacceptable upon closer examination.

This usually led to a reconsidered policy to attempt to first site a temporary, central storage location, while we took a more deliberate and less schedule driven approach in identifying potential sites for a repository. This was also met by resistance in many quarters, among those who felt that it was unconscionable to continue to produce nuclear waste without a high priority program dedicated toward providing a timely repository. Further, there was little tolerance for hosting a storage facility for the nation's high-level radioactive waste, because of the legitimate concern that once the storage facility were agreed upon, the pressure to find a permanent solution could diminish to the point that the storage facility would become the de facto repository.

Thus the national policy swung back and forth between placing priority on disposal and centralized storage, with little progress, but growing experience in the difficulties of siting. Interestingly, the debate at this time was less along partisan or even regional lines, but more a difference among leaders of the Senate, who favored early attention to storage, and leaders in the House, who supported timely repository development as first priority. During this period up until the passage of the NWPA of 1982, spent nuclear fuel continued to accumulate in reactor pools and defense wastes continued to accumulate in a variety of places and forms.

Beginning in 1976, increased attention began toward disposal and funding for activities rose dramatically. Siting efforts to identify promising salt deposits and possible locations on DOE reservations were undertaken that were eventually to give us the nine original candidate sites for the first repository that were in essence grandfathered into the NWPA. The implicit assumption was that at some point, the first site to be found suitable and politically viable, would undoubtedly become the first repository site.

<u>1982-1987</u>

The national policy was set by the landmark NWPA of 1982, signed into law by President Reagan in January, 1983. In one of the most explicit laws ever passed, the NWPA made it clear that the priority for the country would be the identification and development of a geologic repository and it set a most ambitious time schedule for its initial operation—1998. Not unexpectedly, given the intense and divergent views held by many on Capitol Hill and among the stakeholders, the bill contained a number of compromises.

First, it prescribed two repositories, although it authorized only one initially. And it was implicit in the law that if the first repository were to be sited in the West—as was widely expected—then the second repository ought to be sited in the East, particularly since more than 80% of nuclear power is generated in the East. It also stipulated that no more than 70,000 metric tons of waste could be emplaced in the first repository before the second repository was available for operation. This was about half of the total inventory of waste expected at that time and was meant to ensure that ultimately a second repository would be built to provide some regional equity in assuming the burden.

Second, while it did not authorize a temporary centralized storage facility, it did direct the DOE to evaluate and then bring a proposal to Congress on the need for such a facility. And third, it created a funding mechanism whereby in return for paying a fee based upon electrical production from nuclear plants, utilities and defense waste producers signed contracts with the government stipulating that no later than January 31, 1998, the DOE would begin to accept waste for disposal in a repository. Recognizing the inherent political difficulties of selecting any site, the NWPA gave the Governor or state legislature of a state selected for a repository or storage facility the right to file a notice of disapproval—essentially a veto—which could only be overruled by a timely majority vote of both Houses of Congress.

The candidate sites and areas under consideration for the two repositories led to 23 of the contiguous 48 states having one or more potential sites. Thus the five years between passage of the NWPA and its amendment in December, 1987, were about two things—siting and survival. While DOE tried to meet or come close to the many deadlines for site selection mandated in the NWPA, stakeholders in general and affected citizens and their elected representatives in particular were galvanized in essentially every instance to resist any progress in site selection that put communities and states on any candidate list.

Paralleling the repository siting efforts, DOE had responded to the requirement in the NWPA to identify three potential sites for a centralized storage facility, known as a Monitored Retrievable Storage facility (MRS), and announced that it intended to send a proposal to Congress recommending three sites in Tennessee as candidates, identifying a site near Oak Ridge, Tennessee as preferred. Officials in Tennessee were not supportive. The State filed a lawsuit in an attempt to prevent DOE from sending the proposal to the Congress as called for in the NWPA. Interestingly, an independent Commission set up by the local county produced a report stipulating that in return for certain guarantees and benefits, they would recommend in favor of proceeding with consideration of the facility.

As political pressures mounted across the country, and a stalemate was occurring on Capitol Hill, then-Secretary Herrington announced in June 1986, an indefinite postponement of the second repository program siting activities at the same time that he announced three candidate sites as potential finalists for the first repository. The three sites, on an initial list of nine, were located at Yucca Mountain, Nevada; Deaf Smith County, Texas; and Hanford, Washington. All three sites were vigorously opposed by state officials and residents (although not necessarily by communities closest to the sites) as well as by others who represented either neighboring states, states through which the waste would pass on its way to the site, others who took issue with the selection process, and still others who did not want to see the disposal problem solved either this way or at all. Faced with Congressional elections and an escalating national debate, Congress spent the Fall in spirited debate that led to the passage of the Nuclear Waste Policy Amendments Act (NWPAA) in the waning days of December, 1987.

The Amendments Act addressed the three principal siting dilemmas. It validated DOE's indefinite postponement of the second repository siting process, directing DOE to report back to Congress on the need for a second repository between 2007 and 2010. It authorized the development of an MRS, in accord with DOE's proposal, but declared the identified sites in Tennessee to be "null and void" and sent DOE back to begin the siting process again.

Once again providing a compromise to satisfy leading members of both the House and the Senate, it established a Monitored Retrievable Storage Commission to report on the need and desirability of the facility it had just authorized. Limits were placed on its maximum capacity, and new linkages were created to tie progress in siting an MRS to progress in siting the first repository to guard against the MRS becoming a *de facto* repository. And help in siting was provided by establishing the Office of the Nuclear Waste Negotiator who, independent of DOE, was charged with attempting to solicit a volunteer to host a repository or, more likely, an MRS.

But of greatest consequence, the Amendments Act identified the site at Yucca Mountain, Nevada, as the only site to be investigated at present to determine if it is suitable as the site for the nation's first repository for high-level radioactive waste. While the original NWPA has envisioned characterization of three sites, the NWPAA was clear in directing DOE to cease its activities in Texas and Washington in short order. Thus the Congress had in essence agreed with DOE about the second repository program and the need for an MRS, albeit with a new siting program, and had selected DOE's highest ranked site to be characterized for the first repository program. Still, the NWPAA was seen by many as an indication that DOE had not faired well and Congress had been forced to come in to pick up the pieces. Others pointed to the Amendments Act as an indication that the original Act was flawed.

When viewed in the larger context of the country trying to come to grips with selecting a very small number of locations to house the nuclear waste that is scattered around the country in more than 30 states, the need for the NWPA to be followed by the NWPAA seems almost preordained. The Congress could not have passed the NWPAA at the time it passed the original Act in 1982, simply identifying one and only one site for characterization. While the compromise to simultaneously pursue siting of not one but two repositories on priority schedules may seem somewhat naive in hindsight, the country needed to experience the unexpected overwhelming political and societal response and rapidly escalating cost estimates to recognize and tolerate such an early narrowing of site consideration. Similarly, the program was at a stalemate in 1987, with Congress and the Administration most concerned about the situation. Legislative relief was recognized as being necessary by almost all parties.

Thus both the original NWPA and following NWPAA were necessary and appropriate. Neither was perfect, implementation was difficult and subject to endless continuing speculation, but in the end political formulations allowed the program to proceed. It goes without saying, that it would not be surprising to expect future legislative and administrative initiatives to guide a program which, if it stays on schedule, will still last some 100 years.

1987-1993

Following the passage of the NWPAA in 1987, the Department of Energy quickly closed out its activities in all states other than Nevada, as called for by the Amendments Act. The elected representatives of the state of Nevada had been among the most aggressive in fighting consideration of siting a repository in their state when 23 states had been under consideration, and while politicians and citizens breathed a sigh of relief in all the states which had been taken out of the running, understandably state politicians and many citizens in Nevada continued to be most unhappy with the turn of events.

After passage of the NWPAA, the program began to turn its attention from identifying, comparing, and picking sites, to the task of determining what needed to be done to decide if the Yucca Mountain site was suitable for hosting a repository. This meant putting in place a program of research, testing, analysis, and assessments toward that goal which the Nuclear Regulatory Commission would use to determine whether or not the site should be granted a license. The imposing result was a 6000 page Site Characterization Plan. Recognizing that the site, if found suitable, would have to be licensed by the NRC, the chief organizing principle was to gather all the information that might be required to meet each of the many provisions in the regulations. The demands of putting in place a sophisticated quality assurance program occupied the highest priority until it was established, since data collected without such a program would be difficult to rely on during the ultimate licensing proceedings.

While many in Congress felt that they had solved the most vexing problems in passing the NWPA—and indeed they had—it became apparent that a potential stumbling block remained. In order for the program to begin any substantial new characterization activities at the Yucca Mountain site, new environmental permits were required, and in several cases the permits could only be issued by Nevada state authorities.

Thus began a three year process in which the state of Nevada and the Department of Energy traded law suits, Nevada claimed that the program had been vetoed by the state and that the program should therefore be terminated, while DOE countered that the state was in violation by not processing environmental permits in a timely manner. As these developments unfolded, there was little visible work being conducted to determine if Yucca Mountain was suitable, schedules were being extended, costs estimates were rising dramatically, and many of the stakeholders were losing confidence in the ability of the program to carry out its mandate in a predictable and efficient manner. To some it appeared that DOE produced paper rather than progress. Reports from the National Academy of Sciences, the Presidentially-appointed Technical Review Board, and others underscored the angry pronouncement by the most influential member of Congress on this issue, Senator J. Bennett Johnston, in March of 1992, that "the program is broke."

WHERE WE ARE TODAY

With the above lawsuits having been settled in favor of the Department and the necessary permits having been granted by the state (due in no little regard to the Congressional threat to take the authority away from the state), DOE was able to initiate new site investigations for the first time in three years in the summer of 1992. Excavation has begun of a 25 ft diameter ramp which will descend to the repository depth some 1000 ft below the top of Yucca Mountain over the next two to three years to begin providing scientists and engineers with the information needed to determine whether or not the site is suitable to host a repository, and if so, to design the facility and prepare a license application to be filed with the Nuclear Regulatory Commission. An extensive, complementary surface-based program of investigation is also well underway, and it seems clear that the scientists working on the program feel a sense of momentum taking hold.

Current schedules now call for initial operation in 2010, and cost estimates for the characterization phase alone, expected to take until at least 2001, have risen from $100 million to $6.3 billion. However there is widespread skepticism that these dates and cost estimates can be achieved, and there is great uncertainty over whether or not the site's suitability can ever be determined to the satisfaction of the NRC and the other interested parties.

The greatest technical challenge remains demonstrating that the repository will perform as required, isolating the waste from the accessible environment for 10,000 years and more. This is further complicated because the regulation which the Environmental Protection Agency promulgated, and upon which the implementing NRC regulations are based, was remanded by the courts following successful litigation. In the Energy Policy Act of 1992, a three step process was enacted into law to repromulgate the regulations by which the licensability of the Yucca Mountain, Nevada site will be judged. First, the National Academy of Sciences (NAS) has already convened a special panel to make recommendations to EPA as to the content of the new regulation. Then EPA is to repromulgate its regulation (40CFR191) based upon and consistent with the NAS recommendations. And finally, NRC is to modify its existing regulations (10CFR60) to conform to the new EPA standards. This process will take several years.

In the meantime, the extensive site characterization program which has been described in the Site Characterization Plan, will continue to be carried out, with modifications as necessary and agreed to by the NRC. A tunnel-boring machine has been purchased and should begin excavating the several miles of tunnel that constitute the *in-situ* test bed inside of Yucca Mountain beginning in 1994. Thus, with adequate funding, the characterization of Yucca Mountain should continue for the next several years.

However, the earliest the current program could result in a repository open to accept and emplace waste is 2010, not the 1998 that is called for in the contracts between the DOE and the utilities. Several tracks are being pursued to provide a government capability to begin accepting waste by 1998, or as soon as possible. The Office of the Nuclear Waste Negotiator has canvassed the states and Indian tribes throughout the United States, concerning their interest in participating in a voluntary siting process. Four Indian tribe applicants remain actively interested at this time, and two of the tribes, the Mescalaro Apache in New Mexico, and the Skull Valley Goshutes in Utah may soon enter into more formal negotiations. However, state elected officials have expressed serious concern and it remains to be seen if one or more tribes do successfully negotiate an agreement and if such agreements survive the political process.

Therefore, in addition, the Department is investigating the possibility of either siting a storage facility on an existing Federal site, with all the predictable siting difficulties that would entail, or perhaps providing utilities with multi-purpose storage canisters which would be used to store excess spent fuel at the reactor sites and then used as transportation and storage canisters as the spent fuel was later transferred to an MRS and subsequently to the repository. Several outstanding technical and institutional issues remain to be analyzed in reaching any such decisions.

WHAT OF THE FUTURE?

High-level radioactive wastes, both as spent commercial fuel elements and defense wastes to be vitrified already exist. There are approximately 24,000 metric tons of spent fuel in storage and 2,200 additional metric tons are produced every year in return for the greater than 20% of our electricity which is supplied by nuclear power plants. About 85,000 metric tons will produced during the lifetime of the currently operating plants, well into the next century. Estimates vary, but well over 10,000 metric tons of vitrified glass logs containing defense high-level waste will also require disposal. It is notable that these volumes exceed the statutory limits for the emplacement in a single repository.

Utilities, on behalf of their ratepayers, have paid over $7 billion into the Nuclear Waste Fund to date, and understandably argue that the contracts calling for the initial spent fuel acceptance by the Federal Government in 1998 must be honored. Many utilities have or will run out of pool storage space and extensive additional at-reactor dry cask storage will be required, but they would like to minimize those needs. Without timely acceptance, corollary problems may emerge, including institutional resistance to allowing additional at-reactor dry cask storage.

There are a limited number of options concerning what will happen to these wastes. For the near term, they will almost certainly continue to be stored—quite safely—at the sites where they are generated. Should we be successful in siting an MRS by 1998 or soon thereafter, spent fuel would begin to be moved consistent with the size of the facility and the transportation system. Should Yucca Mountain subsequently prove suitable and be licensed, then presumably both spent fuel elements and vitrified glass logs would be emplaced at some point beginning in the early part of the next century. That is the current U.S. vision.

Should nuclear power enjoy a revival in the U.S. and significant numbers of new power plants be ordered, then one could envision a time when reprocessing of spent fuel elements might be considered once again. Even if the spent fuel is emplaced in a repository, it must be retrievable for a minimum of 50 years, so the opportunity to reprocess it would still exist.

Some advocate the introduction of advanced reactors which would be designed and operated to burn more of the actinides than are produced, reducing the ultimate inventory of waste requiring disposal. However, high-level waste would remain, a repository would still be required, and it is difficult to envision a resurgent interest in nuclear power without confidence in the timely existence of a repository.[24] In some cases actinide burning is portrayed as a potential rival to the development of a repository. Caution is advised, since to the extent these arguments undermine the National repository program, they also, ironically, undermine one of the prerequisites to the very resurgence of nuclear power that they seek to encourage.

Some would like to see reconsideration of disposal options that have been evaluated and dropped in the past like sub-seabed disposal, or a new site screening activity to identify additional potential repository sites. Other recommendations have ranged from doing nothing for 100 years in the hope that future generations will be able to conduct the program less expensively and society may be more tolerant,[25] to declaring Yucca Mountain the Nation's nuclear waste site now and putting the waste in the mountain in a storage mode first and determining whether it is a suitable repository site much later. Still others argue for a legislative change to site an MRS next to Yucca Mountain to store the waste on the surface while scientific investigations continue. Continued unrelenting state opposition to the current program, increased impatience in Congress and growing frustration by the utilities may bring these latter alternatives into play.

However, organizations such as the Nuclear Regulatory Commission and the Technical Review Board concur that there is no reason to disqualify the Yucca Mountain site based upon what we have learned to date. So the challenge to the U.S. remains the establishment of a centralized interim storage facility, such as the MRS, and the effective conduct of the repository program.

Numerous organizations and individuals have continued to suggest changes in program strategy and implementation with a view toward increasing confidence in the Department's ability to bring costs and schedules under control, and to provide the vision and stability necessary to gather and maintain progress in the face of the closest of scrutiny. Many, such as special reports by the National Academy of Sciences Board on Radioactive Waste Management[26] and the U.S. Nuclear Waste Technical Review Board,[27] have emphasized the scientific, first-of-a-kind nature of the repository program and have urged the Department not

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[24] Ramspott, Larry, et al., "Impacts of New Developments in Partitioning and Transmutation on the Disposal of High-Level Nuclear Waste in a Mined Geologic Repository," UCRL-ID-109203, March, 1992.

[25] Keeney, Ralph and von Winterfelt, Detlof, "An Analysis of Strategies to Manage Nuclear Waste from Power Plants," Institute of Safety and Systems Management, University of Southern California, January, 1993.

[26] National Academy of Sciences Board on Radioactive Waste Management, "Rethinking High-Level Radioactive Waste Management," 1990.

[27] U.S. Nuclear Waste Technical Review Board, "Special Report, to Congress and the Secretary of Energy," March, 1993.

to be driven by unrealistic schedules. Industry and utility organizations have expressed increasing frustration at the seeming lack of sustained progress, and strive for a solution as soon as practical and within reasonable costs.

At the beginning of 1993, the outgoing Under Secretary of Energy commissioned a task force to recommend a "conceptual revised strategy" for conducting the repository program, to be made available for public review[28]. The task force attempted to construct an alternate program strategy that was intended to better address their concerns of all the organizations and individuals with an expressed interest in the program, The current Secretary of Energy has called for an independent review of the management and financial aspects of the program, and presumably will take advantage of the many reports such as those identified above in modifying the current program. New issues such as the management and disposition of excess plutonium from dismantled weapons may encourage new approaches, but could complicate matters further.

What is clear is that in any event, the repository will not be available for operation in 1998, and that DOE actions taken to attempt to meet the contractual date will be focused on acceptance of spent fuel for extended interim storage or provision of canisters to the utilities to aid their on-site storage needs until the DOE is able to begin acceptance.

SOME CONCLUDING THOUGHTS

As with every other country in the world that is pursuing a permanent solution to the high-level radioactive waste problem, the U.S. continues to focus on the development of a deep geological repository. There remain formidable technical and institutional challenges.

It is often stated that dealing with the disposal of high-level radioactive waste is essentially a political problem. And certainly politics has been a major factor in the conduct of the program. But there are difficult and valid technical, regulatory, and institutional issues to be considered as well. And the program must be formulated and conducted in a manner that is responsive to all dimensions of the issue.

Fortunately, the repository program offers a number of features that are unique when compared to other nuclear facilities and activities. And these features provide the opportunity to carry out the program in a manner that takes full advantages of the differences. Some of the characteristics of a repository are that:

- Once the waste is emplaced, the system is passive, requiring no active measures.
- Processes that would lead to wastes returning to the accessible environment are likely to be extremely slow and would not begin for a long time if at all.
- The facility only becomes a repository at closure, after a final licensing process. This will occur many decades after initial operation. Until such time, the facility will remain open, the waste can be retrieved for any reason, and the entire process is reversible.
- There is no arbitrary cutoff for maintaining flexibility. The facility can remain in an open mode, subject to confirmatory testing, surveillance, and retrieval until future generations are satisfied that they are ready to close the facility.
- Though we will know a great deal at the initial licensing stage, operations and confirmatory testing will greatly add to our knowledge and confidence that the system is performing as expected. The opportunity will exist to optimize the system based upon early experiences, further assure that the system will perform well, design in additional safety measures, or remove the waste.

So unlike a reactor, where the (small) risk is present at the start of operations, for a repository, the long-term risks will only be faced after the facility has been constructed, operated, and tested to satisfaction.

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[28] Task Force on an Alternate Program Strategy, Tom Isaacs, Chairman, "A Proposed Alternative Strategy for the Department of Energy's Civilian Radioactive Waste Management Program," March 31, 1993.

When considered in combination with the concerns and wishes of the affected parties, opportunities exist to carefully craft the objectives and priorities of the program in ways that can lead to better chances of success, without sacrificing the ultimate responsibility to provide for management and timely disposal capability for the waste. The Task Force on an Alternate Program Strategy suggested three principal elements:

1. Carefully Define Success – Recognizing that the repository will not be available until well after 1998, decouple waste acceptance from waste emplacement in the repository. A centralized storage facility or perhaps provision of multi-purpose canisters can provide for timely waste acceptance from the utilities, allowing the repository to focus on incremental steps consistent with a first-of-a-kind facility. In this way, we can take advantage of the learn-as-we-go and reversible features of the repository.

   The current repository program calls for the rather rapid disposal of 70,000 metric tons of waste. Instead, the program could focus on the early scientific and engineering issues to determine the suitability of the site; obtain a license using a conservative safety case as described below; emplace a small amount of waste initially, years earlier, to demonstrate disposal and begin confirmation testing; and build a full-scale facility after experience is gained from this early operation.

2. Define and Demonstrate a "Robust" Case For Safety – Numerous expert individuals and organizations, including the National Academy of Sciences, have stated that it will not be possible to "prove" repository performance in the usual regulatory sense. Further, the use of highly complex and abstract mathematical models and computer codes, while useful for program support, are inappropriate tools for demonstrating performance and alone will not provide the compelling, clear case for safety that is needed to garner public confidence.

   The characterization program needs to focus on the identification and demonstration of the performance of a number of conservative, redundant, and diverse features, both in the natural and engineered subsystems, that together can or cannot be shown to meet or exceed reasonable safety requirements. Characterization tests need to limited to those whose outcome can be shown ahead of time to meaningfully affect either the determination of site suitability or system design. The system also should exhibit a number of characteristics, for example:

   - The system should be designed with substantial conservatism to accommodate expected uncertainties in long-term performance
   - The features should be transparent and demonstrable; features that are thought to provide protection, but cannot be shown to provide protection, are less valuable than features which are more understandable and more clearly shown to perform.
   - System design should be such that uncertainty in performance increases slowly with time
   - System performance should degrade gracefully with error—that is the system should still provide protection should some elements not perform as expected
   - Features should be similar to and consistent with natural analogs to the extent possible, so we can learn how nature has dealt with similar situations over geologic time periods in the past
   - The system should be compatible with international technical consensus

3. Implement the System Incrementally – Recognizing the first-of-a-kind, unique nature of the program and the fact that the facility will be open for generations, start small and build on experience. Begin with a research and development facility, progress to a pilot-scale operation, and then use that base to optimize the full scale facilities for operation.

Finally, recognize and value the views and concerns of those citizens most affected by the program, the local population and their representatives. In most countries, institutional success is greatest where officials are able and willing to deal directly with the local populations.

Even in the U.S., the community closest to the Waste Isolation Pilot Plant (WIPP) and the county originally identified for the MRS, among many others, have been open-minded and have in many cases supported radioactive waste operations.

Even with the best efforts, there are no guarantees for success. It is clear that the wastes can be stored safely for many decades at the reactor sites. And some state this lack of necessity as a reason to leave the wastes there for the foreseeable future. But this country among many others has long recognized the public policy requirement to provide for management and a timely permanent solution. This also suggests the need for thorough contingency planning in the event Yucca Mountain is found to be unsuitable or for any number of other possible events.

This is an experiment in democracy, and the program will be conducted over several generations, ample time for major shifts in societal attitudes and tolerance, and views about the need for nuclear power. There are no substitutes for enlightened leadership. A program that is conducted with integrity and competence will have excellent chances for a timely solution to managing the Nation's high-level radioactive waste.

RESPONSE TO

WHAT WILL HAPPEN TO OUR NUCLEAR WASTE?

Susan Wiltshire

The question posed for this session was, "What will happen to nuclear waste?" I am inclined to say that in the short term, Riley's law will prevail—that is, that nuclear waste stays where it is first put.[29] However, there is cause for hope that in the long term an incremental approach—such as that described the paper by Tom Isaacs of Lawrence Livermore National Laboratory (to which this paper is a response)—will lead to decisions that are technically and scientifically sound as well as publicly and politically acceptable.

This paper discusses a basic flaw in the structure of the nuclear waste management program that may inhibit the implementation of an incremental approach, explains additional reasons for applying an incremental approach rather than an all-or-nothing approach, and notes some changes in public thinking that may improve the likelihood that an incremental approach can be applied.

A FLAW IN POLICY

In the Nuclear Waste Policy Act of 1982 (NWPA), Congress established a separate office—the Office of Civilian Radioactive Waste Management (OCRWM)—within the Department of Energy (DOE) to be operationally responsible for the management and disposal of commercial spent fuel. Unfortunately, Congress did not go further and make OCRWM an independent entity. This is regrettable for several reasons:

- This structure makes the Federal government both the regulated and the regulating entity, creating a perceived and potentially real conflict of interest—a conflict that erodes public confidence in the program.
- Congress must vote to appropriate money for OCRWM's activities every year. Consequently, Congress must review the high-level waste program in detail every year, which ensures that radioactive waste management remains a political issue. Although managing nuclear waste is a public policy issue, the annual appropriations process may not be the best way to review the technical program.
- Secretaries of Energy and OCRWM Program Directors are appointed every four or eight years (or fewer); thus the program goes into "no-decision mode" for six months before elections and for at least six months afterwards when there is a change of administration. Under these conditions, the program has little chance to develop stable policies. Shifting policies make it difficult for DOE to develop long-term scientific and technical programs and be a reliable partner during negotiations with other government entities, such as states and tribes.
- The courts cannot enforce agreements made between the federal government and tribal governments, states, or localities in the same way they can enforce agreements made between a corporate entity and another party. Congress can and has changed and even abrogated agreements. As a consequence, states, tribal governments, and localities may be understandably reluctant to sign long-term agreements with DOE, particularly commitments involving funding, regulatory requirements, and local decision authority, since those agreements could be negated by Congress.
- The penalty for inaction does not fall on parties who have the power to act. Specifically, DOE does not pay an operational or financial penalty for the lack of nuclear waste storage

[29] Secretary of Education Richard Riley, then governor of South Carolina, discussing his experience with the Barnwell Low-Level Waste Disposal Facility and the Savannah River Site in the early 1980s.

or disposal facilities; utilities do. Hence, DOE has no practical incentive for solving the problem; utilities do. Getting the incentives right is important in finding a solution. The Department has many other problems competing for high-level management attention and for the expenditure of political capital. Note that the same situation exists in low-level waste disposal: the responsibility for low-level waste deposition rests with the states, while penalties for inaction fall on the waste generators.

A number of management alternatives do exist, and most countries have chosen other ways to assign responsibility for waste disposal. This is not a new issue; it has been discussed since long before the 1982 NWPA. Indeed, in 1982, during the debate on NWPA, the Office of Technology Assessment recommended the creation of an independent, single-purpose waste management agency.[30] In addition, the Committee on Alternative Means of Finance and Management, mandated by NWPA and appointed by DOE, also recommended a separate agency. It seems unlikely that the current arrangement will change, even now, but I believe it unnecessarily handicaps the program.

AN INCREMENTAL APPROACH

In its 1990 report, *Rethinking High-level Radioactive Waste Disposal*, the Board on Radioactive Waste Management of the National Research Council concludes that although deep geologic disposal is recognized world-wide as the best option for disposing of high-level radioactive waste, the U.S. program is unlikely to succeed:

> "The current approach, in which every step is mandated in detail in advance...is poorly matched to the task at hand. It assumes that the properties and future behavior of a geological repository can be determined and specified with a very high degree of certainty. In reality, however, the inherent variability of the geological environment will necessitate frequent changes in the specifications, with resultant delays, frustrations and loss of public confidence. The current program is not sufficiently flexible or exploratory to accommodate such changes."

The DOE Task Force on An Alternative Program Strategy, chaired by Isaacs, reached a similar conclusion. In its 1993 report, *A Proposed Alternative Strategy for the Department of Energy's Civilian Radioactive Waste Management Program*, the task force indicates that the repository program must be incremental, rather than all-or-nothing.

I agree with the conclusions of those two groups.[31] An additional justification for an incremental approach to repository development comes from another perspective—the need to earn public confidence by bringing the language used in legislation and program plans in line with the reality of the program. Although legislation and program plans have set very firm deadlines for waste acceptance and very certain progress toward that goal, OCRWM's technical program has actually evolved incrementally.

Through the years, the program has had to accommodate changes, with the result that milestones have slipped and plans have altered. Unfortunately, when these changes have occurred—that is, when the program has made changes that may have been wise and necessary from a scientific or policy point of view—the rigidity of the legislated mandates and program plans have made it appear as if the program were failing. This appearance of failure has resulted in a further loss of public confidence. Continued commitment to firm deadlines and unrealistically ambitious, all-or-nothing program goals will raise expectations unrealistically, obscure progress, and further the sense of failure for the program and distrust by the public. Congress and OCRWM need to align legislation, policies, and program plans with an incremental approach.

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30 *Managing Commercial High-Level Radioactive Waste*, OTA-0-172, April 1982.

31 I was a member of the National Research Council Board on Radioactive Waste Management in 1990 and participated in writing *Rethinking High-level Radioactive Waste Disposal*.

CHANGED PUBLIC THINKING

It is both interesting and important to note that as the technical program has evolved, so has society's thinking on the topic. This evolution in social thought in turn affects the way we need to address radioactive waste management. Three key issues stand out: ethical responsibility to future generations, society's views of science, and conceptions of how different interests can and should work together.

The tenor of discussions about the current generation's ethical responsibility to future generations has changed. In the late 1970s and early 1980s, discussions about radioactive waste disposal centered on two basic, widely held tenets:

- The generation that benefits from the waste-generating activity must "solve" the waste problem.
- The best solution is to dispose of the waste once and for all.

In the 1990s, discussions about society's obligation to the future reveal a growing recognition that it may not be possible or desirable to solve such a long-term problem in one fell swoop, once and for all. Rather, many now argue that we must manage waste so that it does no harm, implement solutions that can be monitored and tested over time, and leave future generations options about how to proceed. This way of looking at things supports taking an incremental approach in the technical program.

Substantial changes in the public's views of science and technology have occurred in recent decades that necessitate taking an incremental approach in which the public can be meaningfully involved. In the 1950s, American society in general had a great deal of faith in the ability of science and technology to solve any problems, but this view has changed. Most people no longer perceive scientists as infallible or consider "facts" undisputable. DOE's interested public has become very sophisticated at engaging in discussions about the policy dimensions of multi-faceted technical problems and is especially unwilling to rely on black-box models.

Technocrats are also learning the lessons described in the paper by Prof. Michael Golay, that although technocrats in this country are responsible for addressing problems that contain social components, they are not trained or culturally prepared to address the social components of the problems they address. The ability of technocrats and the public interested in solving technical problems to learn how to talk to each other and to engage in mutual problem solving has been demonstrated in other programs, including some DOE programs.

A wide variety of people are sufficiently interested in nuclear waste to become engaged in the waste discussion at one point or another. These interested parties include government decision makers at all levels, regulating agencies, waste generators, the nuclear industry in general, people who reside or work in the areas in which nuclear waste disposal facilities are proposed, people living along nuclear waste transportation routes, and people who live next to nuclear sites, such as nuclear power plants, research facilities, and weapons production sites. Those interested in stopping nuclear power who view the nuclear waste controversy as a mechanism for halting the industry, and those interested in proliferation and peace issues will also enter the debate over not just where, but whether to site disposal facilities.

Theories about and experience with ways in which this wide range of disparate interests can and should work together have evolved considerably during the last few decades. The old DAD—decide-announce-defend—is no longer considered acceptable in society at large or within much of DOE. A decision process seen as a set of discrete, once-and-for-all decisions, with implementation left to the experts, will no longer suffice. People have recognized that rather than have different parties working in sequence, over the long time periods required by legislated schedules, the most fruitful processes for the interactions of widely disparate interests are processes in which all parties stay engaged throughout, learning to work out solutions cooperatively and in small increments, so that the succeeding steps can evolve. Of course, to make this work, all parties must have a shared understanding of the problem and a commitment to solving it. Building that shared understanding and commitment may be a difficult, but essential, next step for the OCRWM program if it is to implement an incremental approach.

There are good technical and policy reasons for advocating an incremental approach to nuclear waste management, and good reasons for hoping that such an incremental approach can be accepted by the public. I often advocate good planning by quoting Casey Stengel: "If you do not know where you are going, you will wind up somewhere else." In this case, however, I think we may wind up in a better spot by not trying to plan every detail in advance.

WHAT WILL HAPPEN TO OUR NUCLEAR WASTE?

DISCUSSION

U.S. Energy Professional:

I am intrigued with this past panel in terms of these past two talks contrasted to the previous two. I repeat my question of yesterday about whether the military dimension of nuclear power had anything to do with the viability of advanced reactor or waste disposal programs, and whether we can break the waste disposal impasses. My instinct is that there is some connection.

So, I wonder what would be the process of getting the Yucca Mountain spent fuel repository, or the MRS underway in some fashion or other. For example, would it help matters if the plutonium from weapons were being put away forever in the form of logs in a high level waste repository. Similarly, would advanced reactor prospects be improved when they were seen clearly to have made progress in plutonium consumption, rather than having society face an impasse in the management of plutonium pits coming out of nuclear weapons.

Mr. Thomas Isaacs (Lawrence Livermore National Laboratory):

The high level waste disposal program has been cursed in the past by a law of unintended consequences. Many times we would try to do things required in our broad process, and we thought that the results would be good. The reality has turned out not to be so. I think that the issue that you have raised is worthy of serious consideration. It involves many attractive pieces, as well as an interesting technical feature. As I mentioned in my talk, the factor that tends to dominate a repository design most is heat removal. If you put plutonium in the repository you would not have the dramatic heat load to begin with. So, it is an easier problem to demonstrate that you could simply dispose of plutonium potentially as a form of high level waste.

Certainly, I know what the reaction in the state of Nevada would be. They have already been approached on this subject, and have had the predictable reaction of feeling put upon and being treated more and more, from their point of view, like a political lightweight that is going to become the garbage dump of nuclear activities for the country forever. I think that reaction requires some serious consideration. However, having said that, I think that we should consider the political dynamics of creating a situation where the desires of the country can be fulfilled.

Mr. David Leroy (Leroy Law Office):

I offer three quick observations and four recommendations for change. The first observation: if you are pro-nuclear, we have a waste storage problem; if you are anti-nuclear, we have a waste storage problem in this country. There are about 75 storage locations for spent fuel for the 110 power plants and six of them are out of extra space now. By the end of the century approximately ten of them will be out of extra space. By 2010, the year when Yucca Mountain is supposed to open, sixty of them will be out of extra space. At that point, we really will have no alternative, but to turn out the lights, or to begin a round of up-to-sixty battles before local public utility commissions about whether what we have not truly considered to be storage sites at all, will now become *de facto* temporary or permanent waste storage sites. Neither of those is an acceptable alternative.

The second observation: as Susan Wiltshire mentioned in earlier remarks, nuclear waste disposal is dead. It is dead in the United States, is dead in France, is dead all over this world. You simply cannot fail to deal with concerned publics anymore on the waste issue.

The third observation: policy vacillations are killing the waste disposal program, they are killing it in many ways. When I was doing my confirmation study for the position of U.S. Nuclear Waste Negotiator, I went back historically to 1978, and found that there more than seventeen different concepts or acronyms associated with what was then called Monitor Retrievable Storage (MRS). We had seventeen different concepts in that limited period of years between 1978 and 1980.

The WIPP was on again, off again, in again, out again. For the MRS we had six Native American tribes that were interested last March 31st, but nobody has acted concerning this following the change of the national Administration this year. In August of this year two tribes indicated that they were ready to indicate potential MRS sites, and to begin negotiations. In September and October we have been in the process of mining in the underground waste disposal program. The work at Yucca Mountain, to the Administration's credit, has not been second guessed at this point. However, there is an underlying concern that policies could change later.

The first recommendation is that the nuclear industry must reassert itself. This year, the Secretary of Energy will be sued by one or more utilities. This year, the Secretary of Energy will also be sued by one or more public utility commissions seeking accountability for waste disposal. That legal device should not be used by industry, and by the Department of Energy to reallocate the responsibilities of waste disposal. However it is necessary for industry to get more active, and for us to move to the industry those things that could be better done in the private sector. Susan's observation about the difficulties of the DOE being both waste owner and waste regulator are right on target.

The second recommendation: Steven Goldberg, of the Office of Management and Budget, is the most important person in this room. We must have honest cost estimates, and dollars well spent in this program. We simply have not been able to do that in the past. The example of $3 billion spent for a 200 foot long storage tunnel at Yucca Mountain is not a reasonable return on the dollars spent. That money, or some substantial portion of it, must be going to the soft science activities of winning public understanding and building public support. And those honest costs must begin to return waste disposal benefits more immediately and more usefully.

The third recommendation: We must have realistic time tables. We have been constantly fighting among ourselves and slipping task completion dates: 1998 dates, 2005 dates and 2010 dates. Those roving deadlines can become badges for failure. We must once and for all either avoid creating unrealistic completion dates, and instead we must create time tables that are utterly, sheerly, crassly, conservatively realistic.

Finally, I am a fan of seeking consensus, but I must tell you that the voluntary siting process must be enhanced with the irrevocable commitment of this country to ultimate siting of these controversial facilities. We cannot turn around distrust of DOE or any other organ of central authority whether it be government or private in this country. But if we can create effective processes, and begin to reach out to the public, to empower others and to include localities in our processes, we could begin to realize some solutions. Our process is human, and it can be used for waste facility siting instead of against it.

U.S. Energy Researcher:

I am a task force director of the Secretary of Energy Advisory Board (SEAB). It is a group of thirty independent outsiders that were initially appointed by former Secretary Watkins, and more recently a new group has been appointed by Secretary O'Leary to provide the Secretary with advice of a long term strategic nature on issues that affect the Department of Energy. Under Secretary Watkins, the SEAB investigated a number of issues.

The one that I was responsible for directing was a task force that looked at the question of what the DOE could do to strengthen public trust and confidence in its radioactive waste management programs. Thus, when it was said yesterday that one thing the DOE could do would be to stop lying about the WIPP project, the role of tests underground, and to stop obfuscating the costs of the environmental restoration and waste management programs—those ideas resonated with those of the task force.

The task force visited a variety of DOE facilities, both on the defense side at Hanford and Savannah River, as well as on the civilian side at the Nevada Yucca Mountain project. The report of this group is about to be released. I know that a number of you in this room have seen previous drafts. In essence, I think the task force has made a contribution in two ways. Firstly, it has documented the widespread distrust that exists of the DOE. We performed several surveys in addition to talking with more than a hundred individuals who interact with the DOE.

Tom Isaacs' reconstruction of the history of the Civilian Radioactive Waste Management Project is not perhaps the one to which I would fully subscribe, or interpret in quite the same way; but he certainly does point out the very serious difficulties that are created by the institutional context in which that program operates. The task force has recognized this, but it has also recognized that the waste disposal program had the opportunities to do some things that they have not chosen to do. This has had the effect of increasing the distrust of the DOE. Also, it is not simply the program; this has involved the senior managers of the DOE, including the Secretaries of Energy.

The other thing that the task force did was to talk about trust and confidence as if it were a single word. These are really two different ideas and prescriptions for dealing with problems of trust.

Dealing with the expectation of how people will behave towards you is somewhat different from the prescriptions for treating the problems of confidence. What we have found in the task force has been that DOE's waste management programs have no friends. They simply have temporary allies. We have prepared a fairly extensive menu of recommendations that will be forwarded to Secretary O'Leary soon.

Public Policy Analyst:

Well, I do not have any surprises for you. Confidence we have had, have experiences that pre-date the nuclear power program, which is with the nuclear weapons program. If the DOE's handling of the waste problem has been designed to inspire confidence in the commercial side, then I think that we have got another thing coming. We have heard the T word yesterday, which is trillions of dollars. Now that is going to translate into the commercial side where I think it should be quickly understood why the public has no confidence in the DOE's handling of reactor wastes. We have gotten our experience on record already.

There is another T word that has not been mentioned, which is transport. It is very easy to talk about finding a suitable waste disposal site. However, it is a different matter to talk about how to get the waste to such a site. My organization has been dealing with that topic very much concerning low level waste. Also, concerning the high level waste, it is equally problematic. You can choose a site at Yucca Mountain, or wherever else that you think disposal might work. However, tell us how you are going to get the waste to it. Then tell us how many states the wastes will go through. You will find that virtually the entire United States is involved.

Thus, when you are talking about wastes coming from seventy reactor sites, transportation is a major issue. Concern about wastes is not just a political issue that people are trying to use expediently. It is something of very real consequence for people whose backyards will be affected by the train and truck transport of the wastes.

Finally, there is no other technology of the magnitude of nuclear power whereby our generation gets the alleged benefit, for better or worse, of the electricity; and where the wastes, no matter how well you may think it may be stored, is going to impact future generations. It is not surprising, I think, that this is seen not only to be a political issue, but also a moral issue.

So part of the environmental community will not cooperate with finding a so-called solution to the nuclear waste problem until a stop is put to the wastes being created. It makes no sense for us to work with the nuclear power industry to "solve" their high level waste problem as long as more wastes are going to be generated. As far as we are concerned, there is no solution. If you create materials that must be dealt with for hundreds or at least tens of generations, the effect is to impose upon future generations a burden that is simply not fair. We cannot tolerate that.

Now consider the case that the nuclear industry would close up shop. We think that is a realistic solution. Then nuclear power would reduce to involving a communal effort to solve the nuclear wastes problem. Meanwhile, we cannot participate in a "solution" until the stuff is not being created anymore. Continued nuclear power operation makes absolute no sense for us.

Finally, I would like to comment on the profound and extremely troubling reality that we are going once again down to Native American reservations in order to find the spot to put the wastes. I think you all ought to think about that. Why is it that once again national sacrifice settlements are being talked about for Native American reservations. The concept is pathetic.

Academic Socio-Technological Scholar:

I want to put aside my political cap for a moment and speak as an active environmentalist. My experience is that of having been in the middle of the arguments just presented, involving those from one end of the environmental movement wing, to those of Susan Wiltshire's views. I have been co-opted three times into putting aside my reservations, and engaging in a cooperative, creative, forceful discussion with the DOE because I believe that the waste management issue is too important to ignore.

However, every time that I did this—and I am a member of the critical elites on this issue—I was driven away from engagement by the reluctance of the DOE, and to an extent of the nuclear power industry to accept any recommendation which they did not like.

I was marginalised and excluded during the 1970s twice, and in the 1980s once, and I am not alone. I am not a unique member of a community that refuses to be engage in the constructive assistance with this problem. I have disengaged because the DOE's record with those other elites who really would like to contribute to help solve the problem is to reject the reports which you write when they do not correspond to what the DOE wants at that minute. I have been involved with the DOE for a long time. From that experience I will make two points: Point one is that one should be alert for unintended consequences.

The second point is to pay attention to the soft sciences. I am told the reason for engaging the social scientist is so that they can lobby the public for acceptance of the nuclear waste program. This may not be what you intended to say Mr. Leroy, but that is what I heard and it is what many of us hear. Effectively what we are told is you do not want the intellectual and academic; you want an advertising agency. If so, leave me alone and go hire an advertising agency. They sell products to the public. I can tell you what you ought to do instead to make the waste program succeed.

Mr. Leroy:

The DOE and the U.S. Government, and other institutions—new institutions such as the Office of the Nuclear Waste Negotiator are trying to move away from the old concepts of forcing the public or "educating" the public concerning wastes. We are allowing the public themselves to create understandings and situations for a locality, state or even an Indian tribe to participate voluntarily on terms acceptable to them to solve national problems. So, if you heard me say something such that you would presume that the U.S. government would be doing things in the same old way, it is probably because the U.S. government policies as well as my words were not fully developed enough to let you understand that we cannot work in the same old way, and that institutions like the voluntary process and that of letting governors and tribal leaders opt in or out of a solution, upon terms favorable to them, is the only way to go in the future.

The lessons of the past have been that the nostrums that you thought you heard from me do not work, cannot work, and will not work. Yet, we must build processes that do work because we have a problem. I think it is irresponsible for the environmental community to force its own solutions upon the nation, and to attempt to discourage the use of nuclear power technology by opting out of contributing to implementation of those same solutions at a time when we desperately need them.

Academic Socio-Technological Scholar:

I have a question that was provoked by Ms. Wiltshire, but it is actually for Mr. Isaacs. It is about science and engineering advising. I have recently been investigating science and technology advising during the 1950s especially concerning the Air Force. Several committees, some of them ad hoc, and others more permanent, such as the Scientific Advisory Board, were very influential in setting policy for the Air Force, especially engineering and science policy. One committee called the Tea Pot Committee under John Von Neumann played a major role within the Department of Defense in shifting a contract responsibility away from the aircraft industry to the electronics industry and the computer industry.

These committees were mostly made up of academic engineers and scientists, and also of engineers and scientists from industry. In the case of the Tea Pot Committee, the industry members were all from the computer and electronics industry.

My question is, who advises the DOE? I have heard very little about the responses of the DOE to expert advice coming from outside of the department. I did hear reference to the National Academy of Sciences' report. However, I do not know how well the DOE has institutionalized the advisory function. Is it turning to academic advisors; to industrial advisors? There is a record of success with such advice, certainly in the 1950s, before experts were discredited in the 1960s.

Mr. Thomas Isaacs (Lawrence Livermore National Laboratory):

When the 1987 Energy Independence Act was passed, among the other things it established the U.S. Expert Review Board. It is composed of people who are nominated by the National Academy of Sciences, and then selected by the President to serve on a board that is completely independent of the Department of Energy. The Board's sole purpose is to review the scientific technical content and the accuracy of the depository program.

That Board has now been operating for four years. They are not by any means the only board concerned with wastes, but they are certainly the preeminent board, and they have probably offered the DOE as much opportunity to build scientific credibility as I could think of. The Board has had a very substantial impact on our program including that of having the DOE change from its original concept of building vertical shafts down to the repository horizon to going to using the large ramps, which have caused a considerable delay and a considerable amount of expense in the program.

So, I think in many ways the DOE has taken advantage of the Board's recommendations. I do not think that we pay enough attention to the recommendations of that Board or other boards. We have tried to bring in about as wide a variety of experts as we could in order to help us with many of these "ologies," both in this technical review board from the National Academy of Sciences and in peer review panels. But it is not clear to me that we should not do more than that in order to have a more credible and defensible, and maybe even a smarter, program if we were to take greater advantage of such boards. I am not defensive at all. I think it is a good idea. We have done it to some extent. I think we probably could do it better.

I also wish to comment on an earlier remark. It is not helpful to say that we spent \$3 billion for a 200 foot tunnel at Yucca Mountain. Such a remark trivializes the difficulty that the United States has in addressing this kind of a problem. Also, we did not spend \$3 billion for that tunnel. We spent \$2 billion on the entire program—\$2 billion was spent in the U.S. to try to obtain three sites as potential candidates for the first repository program, and also to do siting for a potential second repository program.

I often characterize our program like the British foreign revolutionary war. We line up and march, and the other side shoots us down. We line up and march, and they shoot us down again. So, I have full sympathy with the comments about apparent waste. However, when you work in the government nobody gives you the luxury of saying: "We do not like this particular piece of legislation. We prefer to do our work a different way." The program director who thinks that way has a career half life of about one day. In reality you get along, and if you can, you try to influence legislation. However, you are required by the law to carry out the programs prescribed by the Congress. The programs are created awkwardly because of the very difficult political compromises which have to be made.

Susan Wiltshire was very kind to mention the report prepared by the task force that I had the honor of chairing. If any of you would like copies of the report I will see that you get one. One of the points of that report is that you have to be sensitive to political and social issues. The dynamics of the waste disposal situation is, as such, that you cannot necessarily do what you as a technical person or program manager think is the right thing. Our system does not quite work that way. So, you have to be very careful. That is why we analyze the past very carefully; in order to be credible in the future.

I think that voluntary siting is a terrific idea. I hope that we can actually obtain some sites by the voluntary route. I think that we need to push that activity to the forefront for the long haul. However, I also think that the political dynamics of the country are such today that it could be very difficult to obtain a volunteer site for a repository program. If the country has come to the conclusion that it needs a repository program; then many things will depend upon having confidence that the government is committed to having a repository. At that point, we come up against the very difficult problem of resolving conflicts among states rights, local rights and the Federal resolve. These are difficult issues that we probably will not find a solution for.

Prof. Michael Golay (MIT):

I want to ask Tom Isaacs to comment upon the role of experts and how they can be used. I ask this primarily because this is a topic which came up when I visited other countries which had had trouble, as well as ourselves, in resolving their nuclear power controversies. There are two important roles for experts: one is directly contributing their expertise in the way that was just cited within the waste program, and the other is that which arises when many constituencies contend regarding what the effective policy should be.

In the U.S. until the time of Vietnam, one of the roles which experts played was to serve as lubricants to help get an effective policy into place by making it easier for the different constituencies to agree. In agreeing they would defer to the expertise of the authority figure. It has been alluded to that the nuclear power controversy is part of a power struggle within the American society where one set of factions in that struggle has been aided by the loss of influence of expertise in the sense that I just defined. If we can return to a situation where authority figures and experts can play their lubricating role once again, it could be a useful way of avoiding some of the very wasteful social conflicts, of which nuclear power is a good example. I bring this up because I think that the use of experts really can be made in more than one way, where perhaps the most important use was not picked up in the response to Prof. Hughes' comment.

Public Policy Analyst:

I am serving on my state's low-level radioactive waste advisory committee. We are dealing with the issue of volunteer sites. In our example, the performance of the contractor has been, frankly, as corruptive that of the DOE. The intention was to create a public involvement process for siting which would incorporate honest science and expertise without the corruption of the DOE.

We could examine the entire history of the involvement of the DOE, and of much of the radiation research over the past thirty years or more that has led to difficulties with the public and medical community's understanding of the nature of that most basic problem. Well, all of these things come together in exacerbating the difficulties of nuclear waste siting as has been so well described here today.

I, as a geographer, see the management of reactor waste as a trans-solutional problem. We can observe the DOE's past encouragement of the recycle of radioactive materials. After all, it is a definitional problem. We can turn high level radioactive waste into an economically vital source material with a snap of a finger and a signature on a piece of paper. Then next perhaps we can turn those source materials into what—low level waste. We turn them from being DOE's problems to being the problem of those of us in the states for the disposal of the radioactive nuclear wastes simply by the manipulation of the language as we said earlier today.

This history surely must take us to the beginning of comprehension that indeed we must put a boundary on the waste problem, which is to say a limit upon the quantity of waste which is allowed to be generated. I would underline Tom Cochran's comment that we could have 200 tons of wastes instead of 2000 tons by more of that decision-making within the economic and political realm.

Radioactive waste is a problem of production. I would like to challenge our friends from the utilities who are here, who are living with the headaches of what the nation will do with spent fuel in February 1998; and who are living with the headaches of accumulating low level wastes on site. I propose that you transfer to the DOE the area for waste storage at each reactor site, and let the DOE come to every reactor site and take care of the problem after the reactors are decommissioned. What harm to the nation, to the waste programs would there be to take that waste disposal pause of volunteered moratorium on the part of the utilities.

Perhaps doing this would assist some utilities in dealing with their own financial difficulties, and would aid in the process moving us in the energy conservation, efficiency improvement and alternative energy technologies directions that I think everybody in this room except for those who are religiously inclined to the nuclear power program have come to recognize as being beneficial. What harm would there be for us to challenge the utilities to provide this leadership. I also rather liked Dr. Socolow's comment urging utility leadership in the military realm of advocating no resumption of nuclear weapons testing.

Now, I would like those of you in the nuclear industry to recognize that those of us in the environmental realm are not obstructionists. I suggest you abandon that term anti-nuclear, because all of us are most deeply committed to the sequestration, the isolation, of radioactive waste. Frankly, we do not see a prayer of success in the long term so long as the nuclear waste generation curve continues upward, and more waste is produced cumulatively. So, the charge is really to the utilities and to their public utility commissions to assist in moving this program to a point where it can be solved.

Mr. Steven Goldberg (U.S. Office of Management and Budget):

Since my name was mentioned by David Leroy, I thought that it would be appropriate to respond. With all due respect for Tom Isaacs and Susan Wiltshire, I wonder whether you realize that we have a more immediate problem. This problem arose in 1982 when the Federal Government began to collect roughly 1 mil ($0.001) per kilowatt-hour of nuclear electricity in return for a legal obligation to accept and take title to spent fuel starting in 1998.

For somebody who is deeply involved, it is a very complicated budgetary process. Something that would take me probably two and a half days to explain to all of you is how we budget for the receipts that come into the waste disposal fund. Suffice it is to say that the money coming into the fund is not directly connected to the money going out from the fund. You referred to amounts of about $3 billion for this or $3 billion for that. I think that we are not really talking in those terms. I would rather say that electricity rate payers who gave their money to the Yucca Mountain operation may not be getting an honest return on their investment.

In fact, the federal government has been taking money in as we do for other trust funds whether it is social security or transportation. It is not like having a dollar in, dollar out, or even dollar plus interest out process. It is far more complicated than that. We have a problem regardless of our feelings about nuclear power, about who should control it, and about how it should be used. That question concerns the best way for the government to take the money and use it.

Ms. Susan Wiltshire (JK Associates):

I want to make sure that I was clearly understood when I said what we learned over the years about the possibilities of having an incremental program which may be more successful as it is tried as an alternative strategy. What we have learned about is a new way of interaction, or learning better interactive ways among all parties to make decisions that will meet the criteria for good decisions to protect public health, workers' safety, and the environment; and that are technical and scientifically sound publicly, politically acceptable and economically feasible.

Through multi-interest discussions we have learned a lot about those things, but I am not certain whether the Department of Energy will be able to adopt and implement an incremental strategy of repository development nor one relying upon interactive dialogue. I think that a program of interactive dialogue is our best hope. I think that this is feasible. Then, the question remains of whether there is an ability and a will to go along this path; even though it is more open to us.

Prof. Rochlin has said that I am patient I am really interested in trying to understand problems and seeing my way to solutions; and at that point I have no compelling interest or need to impose what I know upon anyone else. So, I think it is rather a matter that when I understand a problem, I am glad; and I do not have to make everybody else understand things my way too; although if you agree with me that is good—I have no problem with that. One does not have to act upon my understanding, but if they did, I believe that they would be better off.

RAPPORTEUR SUMMARY #2

Kent F. Hansen
Massachusetts Institute of Technology

RAPPORTEUR SUMMARY #2

Kent F. Hansen

Dr. Williams has made the point that the potential for renewables is very large. It has been large for years. It will probably remain so as time goes on. He also pointed something else out, which I thought was very interesting: the appropriateness of scale of the renewable technologies for current needs and the current total environment. And that leads me to ask a question, which is: Will the economies of scale ever return for energy production facilities, or are we permanently embedded in an era of small scale technology? I think the answer is pretty important, but I do not know what the answer is. Perhaps someone else might have an opinion on that.

Dr. Williams also reiterated the view that the decision of what path will be taken in developing the renewables will be dominated by economics and politics, and not by technology. As a technologist, I hear that message over and over again, and I am slowly coming to the conclusion that the intrinsic features of technologies are peripheral to everything else. This is because what we do really does not matter or, at least, not very much. He also pointed out that the R&D costs of pursuing the renewable route are much lower than the nuclear costs are or were. However, that point was contradicted by Mr. Brolin; or at least, he raised the question of whether the investments in R&D are similar for the different classes of technologies.

That leads me to another observation and a recommendation for the Third Conference on the Next Generation of Nuclear Power Technology. I would like to have a session consisting of a series of papers by different authors on the estimated R&D expenditures for different energy technologies. Everybody on everything has different values. I know some people who conclude that every dime ever spent on submarines is part of the nuclear R&D budget. I have very good colleagues who are blessed by not being nuclear engineers, and they think that every dime spent on nuclear physics is part of nuclear reactor R&D. Depending upon your perspective, you may have very different thoughts on these matters. I would be very interested to hear a series of papers on how much is being spent on different technologies.

Referring to the paper by Prof. Lidsky and Dr. Cohn, Prof. Lidsky pointed out the past assumptions about the energy costs of nuclear power, and those about the size of uranium resource base were all wrong. I concur, the assumptions were wrong, but I have very little confidence that the assumptions we make today about tomorrow are any better. In fact, the only safe path is never to predict tomorrow because, whatever you predict, you are likely to be wrong. The space of possible outcomes is larger than our imagination. And under those circumstances, prediction is always error prone.

Prof. Lidsky also highlighted the nuclear power industry's failure to shift technological gears fast enough. At the expense of angering a close friend and colleague, I am going to disagree with him. I find that kind of comment to be superficially profound, but deep down to be shallow. The fact is that any enterprise on the scale of the nuclear industry has enormous investments that cannot be written off overnight without being paid for by someone, either the public or the industry. The posture of being future-oriented is a popular pose. However, I am not sure that anyone's perception of what that future will be is any more accurate today than it was in the past, as Prof. Lidsky has pointed out himself. There is large uncertainty about all new technologies.

In the 1950s, I entered into the nuclear power industry and the nuclear engineering education program. At that time I was widely admired by my colleagues for wearing a white hat. Given the changes which have occurred at social events today when people ask me what I do, I whisper, I do not speak out loud. As with regards to shifting gears technologically, there are possible alternatives.

There was an interesting question raised about the optimal mix-of-resource strategy for lower cost electricity. Lower cost electricity is very much part of the plan to the utilities today. I would add, however, that there is more of interest than simply low costs, for example, obtaining high system reliability is a non trivial problem. A U.S. utility can lose its franchise if it is not reliable enough, and if it has to rely on someone other than itself to provide demanded electricity, it puts its entire franchise at risk. I also think that having flexibility in the face of unusual events is important. We have hurricanes, tornadoes , storms, rain, snow, and whatever—they all could affect the grid. We have world politics that can shift available radium resources, and we have changing economics. I do not think that any utility can optimize its technology mix on a daily basis. It has to do so on long-term basis, and it has to meet other constraints. Least-cost planning is a fine idea but it is not the only criterion which should be used in determining the technology mix.

I now turn to the issue of weapons proliferation. I wish I did not have to talk about this topic because it is a terrible mess. From what I heard this morning, the options space is basically three dimensional. We can vitrify the wastes, we can burn them up, and we can store them. There are technological and economic arguments for a lot of different pathways through this three dimensional space. And again, political factors dominate. In this case, the political factors are more complex than before; for example, the Russian perception of what we do is vital to the decisions we make. The issue is further complicated by international security. Nuclear weapons are sufficient for security, but a lot of people find nuclear weapons provide a contribution to their security, and that makes the question of proliferation more complex. Years ago when I had a three dimensional differential equation, I learned to solve it by separation of variables. In this case, I do not know what variables to separate. I find no consolation in my past trade in mathematics in regard to this subject. There does not seem to exist a single entity capable of making a decision on proliferation. It involves our governments. It involves the utilities. It involves the other governments. It involves the public. It involves everybody. There are, in my opinion, too many players at the table. I cannot think of a constructive way to reduce the number of players. So we have a very complex problem.

The most interesting conflict that emerges through the difference of opinion expressed here concerns the obligation the utilities have with regard to proliferation. One argument being that they should take a leadership role. The other argument is that the utilities have been badly burned in the past by going out in front, and they certainly do not want to go out in front on this one. There was nothing in the session that made me think the issue of proliferation will be quickly, or reasonably resolved.

If proliferation is a serious problem, then waste management is even worse. In fact, it is almost impossible, and compared to my thoughts about it before the session, things are even worse. I heard about Rayleigh's Law, and the law of unintended consequences. I believe there are two other laws that also apply. We had a very astute vice president for research here years ago named Tom Jones. He would invoke Jones' Law which applies to the waste issue. Jones' Law is "friends come, friends go, but enemies accumulate." I also think, with regard to waste management, that O'Toole's Law applies. If you do not know O'Toole's Law, it states that Murphy is an optimist.

I was struck by Mr. Isaacs' observation that it was easier to deal with the local communities than with state governments. I did not hear any discussion on how that might be exploited, or if it should be exploited, but it seems to me that it would be worth pursing. I was also struck with Mrs. Wiltshire's observation about placing responsibility for wastes someplace other than with the DOE. This is a very intriguing and constructive thought with at least one flaw in my imagination. I do not know who else beside the DOE would handle the wastes, and I do not know how to separate management of a new agency from the political process. But, I hope that we will have the chance to talk further about that a little later.

I was also reminded of something Roger Kasperson said yesterday to the effect that the Swedes have been able to make some progress on the waste storage problem. This is interesting, since waste disposal is a sort of a political problem, not an actual problem. It might be valuable to compare the circumstances of Sweden and the U.S. in order to see if there is any lesson that can be learned from what appears to be a progress in another country. Perhaps in the future we could invite someone from other countries to talk about their dealings with that issue.

The discussion today, that followed the presentations mirrors the history of the last thirty years of the waste issue. There are, in my view, irreconcilable differences between people here. They have incompatible assumptions, and incongruent beliefs. What I am struck by concerning the wastes is that there has been no discussion of whether it is a serious technical problem. I do not know how to interpret that. Does that mean that there is a consensus that the technology is in-place, simple; and that the other problems are more important, or is there a belief that the technological problems are so great that the socio-political process must take over? I do not know the answer to these questions.

I will close with one comment with regard to the waste issue. When I was a child there used to be a saying that said, "When there is a will, there is a way." With regard to nuclear waste, I would modify that and say, "Where there is a won't, there is no way."

Prof. Michael Golay (MIT):

I want to thank Prof. Hansen once again. He made what I think is the hardest job in this meeting look easy ; and we should all be grateful.

We are now at the last session of the meeting. It is the one which all of the others lead up to, as we deliberately structured this Conference so that in the preceding sessions we consider questions which are all part of that to be considered in the last session, which is: "What should our future energy strategy be?" The keynote paper will be given by Prof. Neil Todreas of MIT from Nuclear Engineering Department. And the respondent Prof. Gene Rochlin from the University of California, Berkeley.

SESSION SEVEN

WHAT SHOULD OUR FUTURE NUCLEAR ENERGY STRATEGY BE?

WHAT SHOULD OUR NUCLEAR ENERGRY STRATEGY FOR THE FUTURE BE?

Neil E. Todreas

Massachusetts Institute of Technology

RESPONSE:

NUCLEAR TECHNOLOGY AND SOCIAL CULTURE

Gene Rochlin

University of California

INTRODUCTION

Session 7 – What Should Our Future Nuclear Energy Strategy Be?

The future of nuclear power is greatly in doubt. It could flourish in some countries and go out of use in others. The types of power plants conceivably to be used in the future also differ greatly. All of the sessions of the Conference have been structured to address different aspects of the question, "What should our nuclear energy future be?" The purpose of the last session is to benefit from the preceding papers and discussions, by addressing this question.

Predictably, this last session has not led to unanimity, or even general consensus. However, it has demanded that all of those presenting their views had to frame them carefully, and take into account the contrasting arguments presented earlier in the Conference. Through this process hopefully the Conference participants learned of others whose views they might wish to consider in the future, and perhaps the readers of these Proceedings will also reach deeper level of thought in considering our energy future and the role which nuclear power will play in it.

WHAT SHOULD OUR FUTURE NUCLEAR ENERGY STRATEGY BE?

Neil E. Todreas

SCOPE OF THE PAPER

My views on "our nuclear energy strategy for the future" are based on the following interpretation of these key title words:

- "Our" – I take this as the strategy for the United States of America to be achieved by the combined actions of the public and private sectors notwithstanding the fact that many of the initiatives proposed likely demand availability of public funding stimulus. However, directions taken in the expansion of the nuclear industries of Asian and to some extent European countries will affect the options for the U.S. strategy.
- "Nuclear Energy" – Consideration of terrestrial nuclear energy systems that could be commercially deployed for the coming 50-year horizon dictates a focus on fission systems.
- "Future" – Our strategy is to encompass the next 30–50 years. This is the period required by technological, economic and socio-political considerations to implement large scale commercial systems.

The goals which this strategy seeks to satisfy are as follows. They provide the rationale not only for maintaining the nuclear option but for putting in place a research program to provide increasingly improved plants for future deployment.

- Countries with advanced technological capabilities (here I include Russia, China and India along with the more obvious) should exploit their capability to use nuclear power to satisfy a growing portion of their energy requirement and thereby allow other less technically sophisticated societies to use fossil fuels to satisfy their energy needs.

  A prime source for satisfying future energy needs will be electricity. The magnitude of this need could be staggering considering population growth and improvement in the standard of living in developing countries. This need should be met while maintaining acceptable environmental conditions, notably air quality and what may evolve as the necessary constraint on generation of greenhouse gases. Nuclear generation should play a meaningful role among the mix of generating technologies which will satisfy this worldwide electricity need.
- An active civil nuclear energy program should be maintained by the U.S. to provide it with the technical and political basis necessary to exert leadership in advancing non-proliferation goals worldwide.

  The technical character of nuclear energy technology is such that civil and military activities can be commingled to the degree that the political will dictates. Effective leadership on non-proliferation matters first requires the national technical maturity to carefully assess evidence and options, and second the experience and facilities to lead by demonstration.

This scope leads me into the competitive thicket of alternative reactor concepts, an arena that has ensnared many a technological commentator. This is not only due to competitive industrial pressures, but it is intrinsic, I believe, to reactor technology itself. Technically viewed, we are awash in feasible reactor alternatives—probably too many for our own good. Because the requirements of fuel, structure, coolant and, optionally, a moderator, can be met by multiple materials, a large array of feasible combinations exist. Hence, literally hundreds of reactors have been conceived; tens have been built; and, I believe, a score could be commercialized successfully (safely and economically) if experience and sustained resources could be applied to the acquisition of an operations experience base upon which to build a steep learning curve. This bewildering wealth of alternatives is compounded by the ability to "tune" reactor design to create materials, destroy materials, or provide process or space heat simultaneously with or independent of power production. Consequently, this amazing flexibility has led us over the last decade into internecine warfare over reactor technology choices. I will return to this flexibility and rely on it as the springboard from which to propose renewed creative activity later in this paper.

Premises upon which my strategy is based:

- "Our Future" Requires a Present – The role of nuclear energy in the future requires that the existing fleet operate successfully (economically and safely) until a second generation of plants is in place. This requires license renewal and targeted technical upgrading of key systems in the existing fleet.
- The Achievement of "Our Future" Requires a Bridge from the Present – Future nuclear plant designs that will symbolize technological progress equivalent to the propeller to jet transition require at least a generation for development and significant feedback from operation of a prototype(s). This feedback has proven especially necessary regarding environmental corrosion phenomena, large components, and management of plant operation. The fission system serving as this viable bridge must be able to compete economically with fossil, primarily gas-powered alternatives.

  Current realities dictate construction of this bridge on an electricity, not a process heat market, on an abundance of slightly enriched uranium fuel and on a realization that the necessary provision for safety through the defense-in-depth approach confers no overriding safety advantage to any specific coolant approach. Consequently, light-water systems of Evolutionary design are, by far, the appropriate strategic choice to serve as this bridge.
- "Our Future" Is a Long Way Off – It is so far off that we should reopen the consideration of concepts by instituting a technically sound research (not development) program that would include novel light-water cooled approaches. There is time and opportunity to assess whether such approaches can compete over the longer term with gas-cooled or liquid metal-cooled concepts. This research program should have a strong experimental component.
- "Our Nuclear Future" Ultimately Requires an Assured Fuel Supply – Strategically a sustainable nuclear economy will require a breeding fuel cycle. There is no pressing need for a detailed plant design, but key existing infrastructure should be secured and research focused on critical questions of mission capabilities, economics, and safety for fission breeders. For the long term future, it is possible although improbable that electric breeders (fusion, accelerators) may effectively compete with fission concepts.
- A definite distinction is drawn between the research, development and deployment phases. The cost differences for a concept advancement among these phases is enormous—of order \$10s of M/yr for research; \$100s of M/yr for development and \$Billions for deployment. Also, the lead role would certainly switch from government to industry along this trajectory of project evolution as the risks for commercial deployment decrease.

ELEMENTS OF THE STRATEGY

Secure the Present U.S. Reactor Fleet

This certainly requires license renewal for a significant fraction of operating plants to maintain industry scale until deployment of a meaningful number of second generation plants. Further, the economic pressures on the operating fleet require achievement of reductions in operating costs. Finally, definite progress must be made to deploy high level and low level waste disposal facilities.

The specific goals and key development activities targeted to their advancement include:

a. License renewal – Understand the limits on lifetime of pressure vessels, large components and difficult to replace small items (e.g., cabling);

b. Enhanced cost effectiveness of operations and maintenance – Development of nondestructive inspection and monitoring techniques, robotic capabilities to replace humans in remote or high radiation environments, chemistry controls and processes to reduce sources of dose and waste volume, and validated reliability based maintenance programs; and

c. Minimize challenges to safety systems – Provide means for enhancing human and equipment performance leading to safer and more economic operation.

Further, where cost effective, I foresee the integration into the operating fleet of advanced systems and components developed as products of advanced reactor design activity. Advanced control systems are such an example.

Maintain and Modestly Advance the Existing Knowledge of Advanced Technologies

The center of gravity of DOE advanced reactor activity has traditionally rested on liquid metal and gas cooled technologies;

- the LMR is the most assured means for achieving virtually inexhaustible energy generation. It also offers a technically feasible and environmentally acceptable means for minimizing the quantity of actinides which must ultimately receive long term storage or geological disposal. While it maybe shown not to be prudent economically or practically to pursue actinide burning in this manner, its existence as a feasible alternative is valuable to convince skeptics that our reference waste management strategy was not chosen because it was the only course available.
- the MHTGR effort has led to the concept of particle fuel which if successfully developed could provide a high temperature fuel system, and to interesting turbine and recuperator developments pointing toward a direct cycle system.

Neither of these systems, however, is ready to serve as the bridge to our future. Further, with "our future" years off, no imperative exists to mount a development versus a research activity for either. While a design framework is desirable for focusing research goals, the very minimal design activity should be made to suffice at this time.

Consequently, work on these technologies should be of research scope directed at securing the existing knowledge base and solving critical issues of these technologies. This would involve advancing the proposed fuel systems and waste management approaches with attention to proliferation concerns, i.e.,

- the metal fuel and its reprocessing technology for the LMR;
- the particle fuel and particularly the extent of potential fission product-turbine contamination for the direct cycle MHTGR.

Development of both fuel systems requires high temperature irradiation capability. Currently these programs are mounted in the EBR-2 and the ATR. It is ironic that the most modern of our high temperature test reactors, the FFTF, is the first earmarked for shutdown. While the IFR was conceived by the staff of ANL East and West, it is not axiomatic that the requisite physical demonstration programs be executed at the EBR-2 complex. Execution at FFTF would insure use of the superior irradiation facility while serving to maintain an asset of unique irradiation capability for other national nuclear missions. Obvious competition between these sites for research support, the need for construction of a fuel cycle facility at the FFTF, and the personnel dislocations that would flow from adoption of this proposal probably block its consideration. However, in the present climate of decreasing support of the IFR program, such a strategy might bear review.

However, independent of this suggestion to preserve a national high temperature, high flux irradiation capability, the main thrust of the proposal regarding these technologies is to execute research versus development activities on limited critical issues—these are mainly effective high temperature fuel systems with associated waste management and proliferation resistant approaches.

Seek Novel Fission Reactor Concepts

This element is the heart of my strategy since I have opted to establish the Evolutionary LWRs as the bridge to the future. This relieves intense time pressure for identifying a viable replacement technology. Nevertheless, the accelerated development of the smaller passive light water designs, that to many already represent this replacement technology, dictate that this search for novel concepts cannot be leisurely. While this search is framed in terms of integrated systems, it will undoubtedly lead to unique subsystems which would be of general use.

The strategic goals for this concept search should include the following:

1. Compete Economically with the Lowest-cost Electricity-producing Option, while Demonstrating a Discernible Improvement in Safety Over the Preceding Reactor Generation, i.e., the Evolutionary LWR Bridge.

   This is a tall but necessary prescription for viable reactor concepts. Common wisdom in product development is that vision is limited to two to two-and-one-half product life cycles beyond the current product. Stacking of products following the existing LWR fleet (of which plants with small design variants are still under construction in Asia and France), the first is the evolutionary LWRs, the second is the passive LWRs, and the third is advanced (alternative coolant) reactors, I take solace in this wisdom in asserting that the product that will be deployed following passive LWRs is not certain. (In fact, whether the approach of the passive LWR or a variant of the Nuclear Power International's EPR pressurized water reactor being designed to employ a mix of active and passive features will prevail as the second product I take as uncertain.)

   In any event, fulfilling this prescription is not the exclusive domain of gas or liquid-metal cooled approaches. This "advanced" concept search must be open to water cooled concepts even through experience with environmental corrosion and primary system components has been costly. Proposed water chemistry solutions for future systems are not fully assured. Nevertheless, analogous difficulties with gas and liquid metal systems, which become apparent only after long periods of operation, can also occur—witness the experience with the carbon dioxide MAGNOX system, the helium-cooled THTR plant and susceptibility of particle fuel performance to coolant impurities, and possibly the leak in the Super-Phenix sodium system. One should note that this concept of achieving a competitive product by building upon an experience base (LWRs, in our case) is being adopted as the strategy in other spheres—witness the joint White House/Big Three Auto Makers, "... radical new approach to car technology ..." announced September 29, 1993 (*The New York Times*, page D1). This initiative is based on enhancing the fuel and pollution performance of the internal combustion engine to "... result in breakthroughs that are likely to position our American car auto industry to dominate the growing world market in the next century" with products based on this historic engine.

2. Reactor Power Should Be 600 MWe and Expandable to Larger Outputs.

   The proposition of smaller modules grouped together in power blocks of this size has been popular. This design approach for specific concepts has been dictated by fundamental constraints of passive decay heat removal. This necessity has been made a virtue by claims of better match to future power grids, improve economic advantages through modular factory construction and reduced operational staff by virtue of advanced modular control strategies.

   The economic advantages of modularization need not be exclusively linked to power blocks below my target size as demonstrated by existing work on current evolutionary and passive LWRs. Further debate continues on the economies or diseconomies of scale. Obviously the U.S. experience has egregious examples of the diseconomy of scale, which resulted from the loss of owner control of the construction process. Conversely, some U.S.

and most international construction was managed such that it benefited from the economy of scale. Obviously there is a reactor size at which the plant complexity limits the achievable economies. I believe, however, that this size, rather than being dictated by modules less than 600 MWe, is far larger than 600 MWe.

The flexibility to match to the needs of power grids is a benefit of smaller modules, but is in my opinion offset by the fundamental character of nuclear power, creation in the core of an operating reactor of a large quantity of fission products. For a given power demand, I believe it is prudent to maintain the generated fission products in as few vessels as possible, and thereby concentrate safety features and systems on fewer vessels. Considered from this regard there is no overriding virtue to multiple modular reactors even given the enhanced passive decay heat removal capability regime that these smaller reactors can achieve. The match to future power grids is an argument of merit, but the effective grid size of the future for a future power generator, is by no means certain. Perhaps a better argument for smaller modules is their reduced capital investment requirement, but such a reduction may not be a priority for generating consortium of the future. Finally, I note the recent proposal from CRIEPI (*The Energy Daily*, September 21, 1993, page 3) to consider small scale, compact reactors because of their potential for district heating through urban siting and for deployment in developing countries because of their smaller required capital outlays. I consider both these markets for nuclear power problematic and not a sufficient basis to stress small reactors of under 600 MWe.

The goal of a 600 MWe minimum but expandable reactor seems reasonable in light of the constraints of flexibility to match power grid needs in viable national markets, the economics of construction and operation and the achievement of discernible safety advantages.

3. The Reactor Can Rely on a Mix of Active and Passive Safety Features.

In our quest for quantifiable safety advantage, the notion of ultimate reliance on passive safety features has gained preeminence in the U.S. Adoption of this design principle has strong roots in the observation that reactor risk from design characteristics has been driven below that stemming from human error, and the corrective action is to eliminate this potential by substituting reliance on features that operate on inherent physical principles. I would adopt the principle of allowing a mix of active and passive features that was sufficient to meet safety and economic objectives. Reasons for allowing this mix are as follows:

a. It is not obvious that passive features are the only way, or even the best way, to address the real problem of human error. Designers may be fallible in their determination of circumstances under which human intervention can and cannot help. Only recently have we intensely focused on the human performance issue; hopefully, we will find improved options to address this challenge.
b. The confirmation of adequate response of passive features to all possible system states is a daunting task because of the relatively weak driving forces involved in passive feature responses and the difficulty in establishing all possible system states and their probability of occurrence.
c. The use of active means to respond to selected upsets requires modest energy requirements and component designs, and the requisite system response can be reliably assured by available approaches.

Proponents further link the adoption of a passive feature strategy to achievement of a simpler and, hence, less costly reactor system. The gains in simplicity and hence cost are very desirable outcomes. If adoption of passivity were to arise out of a demonstration that this were the unique or most effective way to meet requirements and achieve these outcomes, then I would accept this outcome. The horse would have been put before the cart. However, I feel that use of passive features is being imposed as a precondition to novel concept development in the U.S., although certainly not in Europe.

4. The Reactor Design Should Meet Life Cycle Requirements.

   It is now commonplace to speak of the need to close the nuclear fuel cycle. This principle imposes this need but does not dictate a specific disposal option. The obvious candidate is the proposed Yucca Mountain geological storage repository. I do not have in mind an alternate disposal option—rather, I wish to force an early evaluation of the feasibility of the waste management processes and procedures allied with every proposed concept. I note, perhaps by necessity, that such an evaluation is part of the Integral Fast Reactor (IFR) program plan.[32]

These are the goals for the novel fission reactor concepts. What are the preferred design choices to concept technical evolution? I suggest the following:

a. Utilize Fuel Designs that Enhance Proliferation Resistance.

   Enriched uranium is abundant now and for the foreseeable future, considering conversion of weapons stocks and the status of new enrichment technologies. U-235 fuel with low or modest enrichments (certainly below 20%) would be used. The utilization of the Pu-239 or U-233 cycles do not now promise systems of commercial success and enmesh (for Pu-239/U-239 breeding) the enterprise in proliferation scenario controversies.

   The suggested path will, of course, lead to plutonium generation, but it would be desirable to enhance in situ plutonium burnup. This path also is not intended to preclude loadings of plutonium to deplete stocks from fuel cycle operation of the existing fleet or from weapons inventories. Rather, this path is suggested in view of the reality and potential for ample U-235 stocks and to minimize additions to Pu stocks.

b. Utilize High Temperature Capability Fuel.

   Fuel temperature design limits become a dominate constraint on the ability of a reactor system to dissipate decay heat using conduction and radiation modes of heat transfer. Particle fuels offer the means to achieve high temperature design limits. However, the most recent tests of U.S. particle fuel demonstrate the large amount of effort still necessary to define a specification whose achievement will assure satisfactory commercial quantities of fuel to that specification. While a gas coolant is obviously compatible with the graphite coatings and moderator of this system, carbide-based particle fuels can also be used with water coolants and perhaps in conjunction with effective cladding around graphite moderator (remembering the Hallam experience) with sodium coolants.

   Further, such fuels allow achievement of higher cycle thermodynamic efficiencies with the employment of the super-critical water cycle or the employment of liquid metals in their normal temperature range. For these applications careful attention must be given to clad performance and substitutions for Zircaloy employed—substitutions, possibly beyond stainless steel, which achieve higher performance potential.

c. Employ a Containment Vessel.

   While particle fuel provides a measure of containment, I do not believe it is possible or prudent to achieve the requisite public health and safety protection from these X-billion containments themselves. By possible, I question whether a manufacturing quality assurance program will ferret defect fuel in the Nth core lot considering the economic penalties of excessive inspection sample sizes and the possibilities of human error now focused on the manufacturing and inspection floor. By prudent I believe that the public will require and our designs should prevent releases of activity from a plant, even those at the radiologically insignificant level of primary system

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32 ANL-IFR-77, "A Strategy for the Qualification of IFR/ALMR High-Level Wastes for Repository Disposal," J. Laidler, et al., October 1992.

circulating activity. Containments should be designed to a level of performance which removes the perceived need for evacuation under accident conditions.

d. Simplify the Power Cycle Configuration.

Simplicity is a dominant current theme in reactor development. Employment of the direct cycle configuration offers the appealing potential for simplicity and cost benefits. In practice the complexities of in-vessel components to condition the vapor (BWR) and in-vessel recuperator designs in gas Brayton cycles (GCR) diminish this appeal. Nevertheless, the promise of future developments lead me to favor directing attention to the direct cycle configuration.[33]

e. Strive to Eliminate the Generation of Combustibles within the Plant.

This last path is perhaps the most problematic to implement, yet I include it since my overall target is a novel concept search. In the current regime of designing for severe accidents, loadings on the containment from hydrogen and carbon monoxide are significant. The generation of these materials compound efforts to track the sequence, the consequences and the mitigation strategies for dealing with severe accidents. Elimination of combustibles would require a wholesale reassessment of reactor materials. Replacement of metal clad is required—ceramic oxides are an apparent candidate, albeit with many current drawbacks. In this regard, oxide-based ceramic composites have been proposed[34] and investigated to a limited extent. Graphite materials would fall victim to this exclusion principle. More specialized concretes, which minimize or exclude limestone producing CO for construction of basemats, or core restraint devices of other materials would be sought.

Invest for Breakthroughs in Critical Disciplinary Areas

The previous bullet on novel fission concepts addresses a wealth of technically specific research areas. Underlying all reactor concept activity are a number of disciplinary areas whose advance would benefit the entire enterprise—the evolution of novel concepts, the introduction of evolutionary reactors, and the successful operation of the existing fleet. These areas are:

1. HUMAN RELIABILITY

Plant design has rapidly evolved to the condition where risk contribution from equipment has been driven below that from human reliability. While we have had success through training and human factors measures dealing with unintended unsafe acts, we do not know how to deal with intended unsafe acts. In the NRC view, this is primarily a focus on commission errors although the state-of-the-art is that even the semantics are unresolved[35] as evidenced by Dougherty's needed definitions of commission error and cognitive error.

Advances in this area will be very difficult because of the lack of overriding governing principles to guide model building. On the other hand, the INPO activity has led to the documentation of many relevant events and the presence at almost all utilities of a dedicated human performance enhancement engineer. These elements provide a rich mine of data and experience to test and advance hypotheses toward achievement of the goal of a cognitive model for nuclear plant application.

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[33] A word of caution here regarding the intractability of coolant chemistry control in the direct water cycle. In such an open, oxidizing environment, achievement of satisfactory chemistry control in inherently more difficult than in a closed systems and may inevitably lead to recurrent episodes of undesirable performance.

[34] Herbert Feinroth, "Filament Wound Oxide Ceramic Composites as Water Reactor Fuel Element Claddings," International Conference on LWR Fuel Performance, Halden, Norway, June 1991.

[35] E. Dougherty, "Context and Human Reliability Analysis," *Reliability Engineering and System Safety*, Vol. 41, pp. 25-47, 1993.

2. QUANTIFY DIRECTIONS FOR AND BENEFITS OF DESIGN SIMPLIFICATION

Every designer has an intuitive feel for the means for achieving simplification. Being subjective, however, this feel does not produce a universal measure. The design process being one of multiple tradeoffs can hardly be dissected and quantified. Nevertheless, the evolution of the nuclear plant design process could greatly benefit by whatever rigor could be injected to amplify the starts which have been made[36] to defining such measures.

3. COMMUNICATION OF RISK

Our industry increasingly characterizes risk and comparatively assesses alternative paths for risk minimization in probabilistic terms. While this is proper for technical communication between specialists, it tends to increase our difficulties in making knowledge of advances in our technology accessible to non-risk specialists in other technologies and to the public.

The NAS characterizes the point in the process of handling risk where communication breaks down as "risk characterization" and is about to engage in an initial 2-year multi-U.S. agency study of this point. The goal is to assess opportunities to improve risk characterization to make scientific information on risk more accessible to non-specialist risk managers and the public. Recommendations will be forthcoming for improving the process by which scientific information about a risk assessment, a PRA, is presented to expert and lay risk managers and decision makers.

While these recommendations do not yet reach communications to the public, they are a vital first step to addressing this area. An NAS study is not enough—it only gathers and interprets existing information. The nuclear enterprise should engage in research to develop needed new information.

4. HEALTH RISKS OF IONIZING RADIATION

Underlying the public concern with nuclear energy is the expected consequences of exposure to ionizing radiation—direct, latent and possible genetic effects. Compounding the public concern is uncertainty that authority figures have established safe levels of exposure. This uncertainty has been periodically reinforced by international and national Commission revisions, downward, of allowable exposures of certain groups of workers and general population.

A reinforced effort to quantify these risks, and importantly the level below which biological processes are sufficient to repair radiation effects, would be very useful if not essential for the future expansion of nuclear power. It would be equally useful to expand analogous efforts for fossil fuel alternatives.

5. STANDARDIZATION BEYOND DESIGN

Standardization has been adopted as a principle of the U.S. ALWR program, both at and beyond design. The NRC's design certification program effectively limits the generation of design variants by the heavy price in regulatory review and potential for public re-review which proposed variants could introduce. Further into operation, the benefits which accrue in areas such as standardized training, spare parts, operating procedures and repair techniques are expected to be sufficient incentive to maintain the standardization regime even between a number of non-connected operating entities. Finally, means are being considered, presumably by convoy concepts to allow innovation, albeit controlled design evolution.

I see adoption of standardization as necessary. I see the accommodation of factors such as those mentioned above to maintain standardization well into operation as possible. However, I am not sure that all obstacles can be accommodated with the knowledge at

[36] M.W. Golay, P.H. Seong and V.P. Manno, "A Measure of the Difficulty of System Diagnosis and its Relationship to Complexity," *Int'l J. Gen. Systems* 16 (Jan/Mar 1990): 1-23.

hand by negotiation among the relevant parties. I think it prudent to commission a study of the standardization process, its challenges and the methods currently identified to meet these challenges as insurance to assess where more basic study of this process in the current nuclear context would be prudent and productive.

Provide for the Creation of Necessary Human Resources

All the research components suggested earlier require educated, dedicated investigators for their achievement whether they are executed in industry, national laboratories or universities. These investigators should be discipline specialists with a significant understanding of the context of the nuclear systems to which their work contributes. Consequently, graduates of nuclear engineering programs or departments are needed in consistent, non-insignificant numbers.

Such organizations are under increasing pressure today from administrators experiencing shrinking resources and increasing demands from other, more popular, technologies. In the face of these choices, administrators must see support forthcoming to their nuclear units from the industry and government before they are willing to commit their resources and personal prestige to sustaining these nuclear engineering departments.

These nuclear academic units are still attracting a satisfactory number of qualified U.S. students. Industry and government must resolve to provide research support to these students and their faculty supervisors to provide for adequate human resources throughout the institutions engaged in nuclear activities.

Consequently, financial support for university academic nuclear departments in the form of research grants, fellowships, and university reactor operation are a vital part of our future nuclear energy strategy.

CONCLUSION

The institution of a technically sound innovative reactor concept research (not development) program is the novel proposal here. The other elements of the strategy—secure the present U.S. reactor fleet, maintain and modestly advance the existing knowledge of advanced technologies, and invest for breakthroughs in critical disciplinary areas—are reorganizations or, in some cases, reaffirmations of existing programs.

This novel concept research program is proposed to provide ideas for concepts to follow the deployment of Evolutionary LWRs and possibly Passive LWRs. The decline of our technical infrastructure and the novel character of the proposed research makes it prudent to actively utilize university teams in this activity. An effective programmatic approach would be the creation of several balanced industry/laboratory/university teams to stimulate the process.

RESPONSE TO N.E. TODREAS

NUCLEAR TECHNOLOGY AND SOCIAL CULTURE

Gene Rochlin

GLENDOWER. I can call spirits from the vasty deep.

HOTSPUR. Why, so can I, or so can any man; But will they come when you do call for them?

GLEN. Why, I can teach you, Cousin, to command The Devil.

HOT. And I can teach thee, Coz, to shame the Devil by telling truth.

Shakespeare
Henry IV, Part I[37]

INTRODUCTION

My placement in this program, as the last respondent on the last paper, provides an opportunity to comment not only on Prof. Todreas' thoughtful presentation, but on the general trend of the discussion over past couple of days that is simply too tempting to resist.

The week after this conference, Californians voted on a plan for educational vouchers. As it turns out, it was defeated, but possibly because it was badly drawn. It is sure to come up on the ballot again. California and other states have voted in term limits for legislators, and both this matter and voucher plans will certainly be on the ballot in a number of states at the next elections.

What does this have to do with a conference on the future of the nuclear industry? Probably not much from the perspective adopted by most of the speakers at this conference, in which each power plant is seen only as a single plant, a single case, a single argument over utility financial exposure, licensing and siting, or public opposition. But nuclear power plants are not single, isolated technical creations. They are part of a nuclear power system, an interlinked complex of many activities, ranging from licensing and regulation to fuel production and waste management, that ties each and every plant into a web of social and political as well as technical activities that make up the nuclear fuel cycle.

SOME BASIC CRITERIA

The relevance of the recent California initiative, and those in other states, lies in the common political trend they expose—a still growing public mistrust not so much in government per se, but the in large, centralized, semi-permanent institutions that have increasingly characterized our modern, technologized society.

But which of the several voices that have been heard over the past two days comes closest to addressing this particular perspective? There has been the reasoned voice of the engineering community, proceeding as always carefully from the present system into the future by incremental technical and system advance. Also heard has been what I might call the "National Academy" voice, addressing matters from the top down in measured cadence.

This latter voice, familiar in tone and incremental and approach is quite familiar to me. In its most recent manifestation (National Research Council 1992), it argues that at the minimum the following criteria must be met if nuclear power is to move ahead, or at least to survive as a real option for the United States:

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37 Act III, Scene I.

(0) The first point is not really a criterion, but an over-arching rule: Do not tell lies, or hide problems.

The only thing worse for public credibility than having trouble is being caught out in efforts to suppress it. Public suspicion is one reason why nuclear regulation in the United States has been designed to be as adversarial as it is (Gilinsky, 1992). Moreover, problems with the (unregulated) military programs also seem to spill over to the commercial industry, on the grounds that the technology is not all that different. In this regard the most recent disclosure about rusting fuel elements at Department of Energy production reactor sites is very troubling indeed. So long as nuclear power is perceived to be an integrated system, suspicion of anyone leads to mistrust of everyone.

(1) Be perceived to operate with complete safety and stability to build confidence.

This is an extraordinarily demanding condition for any industry to meet (La Porte, 1988; La Porte and Thomas, 1991). Some might even consider it to be an unfair and nearly impossible one. But fairness is no longer an issue here; confidence-building is. Unless confidence is rebuilt first, there is not likely to be enough public support to allow the industry to move to a generation of inherently safe reactors, even if they are technically and economically feasible.

(2) Be perceived to be moving forward toward solving outstanding problems such as waste disposal in a reasonable time frame to build credibility.

The question of how to rebuild credibility is neither a simple nor a straightforward one. It means regaining not only public confidence but public trust. Meeting both of the preceding conditions is a necessary prerequisite, but not a sufficient one. It is almost certain that it will require negotiation with public and political bodies about the design and implementation of future programs, e.g., waste management, to ensure that they believe that their concerns have been taken into account from the outset.

(3) Come to terms with the linkage between civil and commercial fuel cycles and technology and possible military and weapons activities.

This may well mean devising fuel cycles and reactor types that are seen to be more resistant to nuclear proliferation, instead of pushing for plutonium-fueled cycles or wide use of mixed oxides. It also means making sure that military reactors and military wastes are given the same critical oversight and regulation as the civil program.

(4) Come up with credible plans for a nuclear future that incorporates reactors that people might want to build, that utilities might want to buy, and that the public might accept, used as part of a balanced energy and environmental strategy rather than substituting for it.

In this regard, it is encouraging to note an increasing unwillingness in the nuclear engineering community to allow the rhetoric of public polarization to pose nuclear power and small scale renewables as competing rather than complementary strategies. Not all industry actors have been so disciplined. What has not changed as much is the historical tendency to let technical or programmatic logic determine the course of research and development, and then to seek public "acceptance" of what it is that has been developed. This in turn leads to a more general rule:

(5) Push less and listen more.

It has always been my understanding that the proper purpose of engineering is to build things people want. As Prof. Hughes pointed out, the techno-modern era in which the public seemed willing to accept whatever it was that engineers and industrial entrepreneurs wanted to build would seem to be over, at least in this country. This could mean actually trying to determine what reactor design, operating conditions, and fuel cycle parameters are compatible with the desires and fears of political and public bodies want, rather than trying to out-think them with a design optimized on technical grounds and trying to convince them that what you have is what they need.

How does this list match with the ideas presented by Prof. Todreas? Some of them are incorporated implicitly or explicitly. Others are more or less external to the paper. This is not too surprising, since the tone of his paper is very much in the thoughtful, "National Academy" tone of voice. Nevertheless, he also raises a few other points that are more interesting and certainly worth noting in the light of the above:

(a) If there is to be a new reactor design, match it to existing technological and industrial culture as well as to capacity needs and grid specifications.

(b) In arriving at new designs, question such supposed cultural "givens" as the need to demonstrate technical leadership to achieve non-proliferation goals.

(c) Build a bridge to the future upon existing designs, consistent with (a) and (b) above. This means pushing forward with the Advanced Light Water Reactor (ALWR) design rather than trying to radically reconfigure existing industries and institutions in the short term.

(d) Seek and argue for a best path to a visionary nuclear future, rather than trying to let the choice of easiest path determine the outcome.

I find his emphasis on culture particularly intriguing because my own work on technical organizations and in political economy has increasingly been drawn to the study of technical and operational culture. And that is the voice in which I would like to bring to the discussion. But first, since my nuclear engineer friend has sallied into the thicket of culture, I might as well counter-move in the woods of technology.

A common thread through this paper, and, even if implicitly, through many of the other technical presentations and discussion at this meeting is the persistent notion that the present generation of uranium-consuming "burner" reactors are only an interim step on the way to the real goal—which remains, for many, the liquid metal reactor (LMFBR), or some other high-tech breeder based on a fuel cycle that circulates plutonium.

The problem with this particular technology is not the nuclear equipment, or its design. It lies with the social and political implications that make a "technology" that is in wide at least as much a form of social and political organization as a technical and industrial one. The usual lexicon invokes the notion of "RD&D," as if that phrase were an inseparable one representing the logical sequence of events. But research is just research, done particularly well by large research universities and national laboratories. Development is just another way of phrasing the engineering effort needed to turn a laboratory prototype into something that a real industry could construct, maintain, and sell at a profit. It is at the point of deployment (or, in some cases, at the point where there is general recognition that the product could or might be deployed in the real world). It is at the point where the equipment starts to be used widely as a marketable and not experimental artifact, and networked into the broad range of other activities that support it, repair it, and provide an interface to the users, that it gains social and political dimensions that have proved so problematic in the history of nuclear power.

This echoes another voice that has been heard from time to time over the past two days, the critical social voice warning that the shape of future nuclear power technology, indeed the whole question of whether the nuclear industry has a future at all in the United States, may depend on issues so broadly defined in social and political dimension that advances in reactor design or technique will have at best only a marginal effect. There has not been enough engagement in the wider discussion of setting nuclear power generation into a the broader context of social and political as well as technical issues that must be considered in shaping America's energy future—including such outstanding problems as waste management, proliferation, plutonium use, risk acceptance and communication, and even the future of renewables.

But what I most miss is response to a similar voice that has been raised at this conference twice—once by Professor Hughes as a general framework and again by Prof. Kasperson in specific context—without engendering much response. The substantive question raised by this voice is whether the matter of exploring a potential "next generation" of nuclear design can be addressed at all without first addressing the degree to which existing or planned activities are or will be socially and politically compatible with the cultural milieu in which any large technical system must operate.

NUCLEAR TECHNOLOGY AND SOCIAL CULTURE

Having attended four conferences on the history and development of large technical systems, two of which are already in print (La Porte, 1991; Mayntz and Hughes, 1988) and two of which are forthcoming, I can assert with some confidence that the cultural study of large technical systems is still in its comparative infancy. Let me therefore make explicit the degree to which my overall argument depends on a series of hypotheses. Starting from the very beginning, these are:

H1. The grid-group analysis of political culture mentioned by Prof. Kasperson and originally developed by Mary Douglas (1970) is an appropriate one for studying the cultural milieu of large technical systems.

Figure 7.1 displays the Douglas grid-group typology as expanded by more recent authors seeking to address technical and industrial societies (Thompson, Ellis and Wildavsky, 1990). "Group" is a measure of the degree to which the individual interacts within a social unit. Strong group cultures promote interaction, cooperation, and community. Weak-group cultures promote independence, competition, and individualism. "Grid" is a measure of the character of the interaction. Where grid is weak, constraining rules and formalisms tend to be low, and the system egalitarian and open. Where it is strong, formal constraints and binding rules are numerous, and the system tends to be stratified and rigid. The four boxes illuminate four paradigmatic cultures: Hierarchies, in which complex groups are formed; egalitarian societies, in which collective action and communal principles are dominant; individualistic societies, in which markets and other forms of competition are most important; and fatalism, dominated by fragmentation in which isolated individuals are constrained without sharing power.

My assertion is that technical cultures and technical properties can be mapped over all dimensions of the space. This goes well beyond the overly simplified assertion made in *Risk and Culture* (Wildavsky and Douglas, 1983), that technical debates, including those over nuclear power, are to be viewed primarily as tools for exploring a broader struggle between free-market and egalitarian ideologies over the cultural shape of evolving modern societies. It is more in accord with the extension of the definitions by Thompson, et al., (1990) to take into account four distinct forms of rationality: procedural (hierarchy), critical (egalitarianism), substantive (individualism), and fatalistic (fatalism).

H2. Technologies are forms of social, political, and cultural organization.

This builds on the original argument of La Porte and others, that it is insufficient to take "technology" to mean only the technical components and the technical inter-connections of a large technical system such as the nuclear fuel cycle (La Porte, 1982; La Porte and Consolini, 1991; Rochlin, La Porte and Roberts, 1987). Technology is a word rich with cultural meaning; it implies social function and political implication as well as economic costs and benefits, risks, and psychological perceptions. An individual nuclear reactors is a technical artifact. Nuclear power, at industrial and commercial scale, is a technology, whose social and cultural dimensions are inseparable from its technical and economic ones.

H3. Technologies can only gain and maintain public acceptance in wide use if their socio-cultural and socio-political characteristics are compatible with the social and political culture in which they are deployed.

GRID (Character of the Interaction)			
	Strong	**FATALISM** Fragmentation, Stratification	**HIERARCHY** Complex Groups, Bureaucracies
	Weak	**INDIVIDUALISM** Markets, Competition	**EGALITARIANISM** Collectivities, Community
		Weak	Strong
		GROUP (Social Incorporation)	

Figure 7.1. Grid-Group Typology.

Source: Mary Douglas, *Natural Symbols*, London: Barrie and Rockliff, 1970.

In a forthcoming article (Rochlin, 1994), I argue that differences in host culture were the primary reason that France have been able to deploy nuclear power at wide scale and with comparatively little public opposition while the United States, Germany, and Sweden were not. I will not repeat that argument here, except to point out that it centers on the persistence in France of centralized government and technocratic elites that was unique among developed, non-Communist societies (Crozier, 1967; Thoenig, 1987). Similar arguments may also apply in the case of Japan, but that remains very speculative in the absence of any firm data.

From these hypotheses, and a very tentative (and no less hypothetical) effort to build on the cross-cultural analysis of other sociologists and political scientists who have focused on other, less technically sophisticated cultural artifacts and industries, I arrive at the heuristic diagrams shown as Figures 7.2 through 7.4.

Figure 7.2 shows the same array as Figure 7.1, modified to specifically analyze only the technological dimensions of culture. The axes have been relabeled to take into account the degree to which cultures are willing to comply collectively with the authority of technical elites (group) and/or to accept the authority of constraining, centralized control (grid). I have also sketched my own analysis of the region of the space that allows compliance with the socio-cultural and socio-political "demands" of operating three different types of nuclear power systems successfully, reliably, and with general acceptance of the legitimacy of engaging in the activity. They have been identified in terms of the fuel cycle, since it is that set of activities external to the reactor that tends to have the greatest social and political impact in normal operation. The shape of the curves implicitly incorporates the further hypothesis that there is a certain degree of fungibility between formal control and social compliance. Note that reactor design *per se* is not really a factor. The power reactors themselves are treated in this analysis as simply an (important) element in the overall nuclear power system, a defining, but not determining artifact in scoping the boundaries of commercial nuclear technology.

Figure 7.3 is yet another heuristic, based largely on the research of others (Fujita, et al.,, 1992; Hofstede, 1979; Hofstede, 1991; Lammers and Hickson, 1979; Louis, 1983; Maurice, et al.,, 1980; Tayeb, 1988). It attempts to array the technical culture of several different countries along the grid-group dimensions proposed by Douglas. As with Figure 7.2, it has been modified

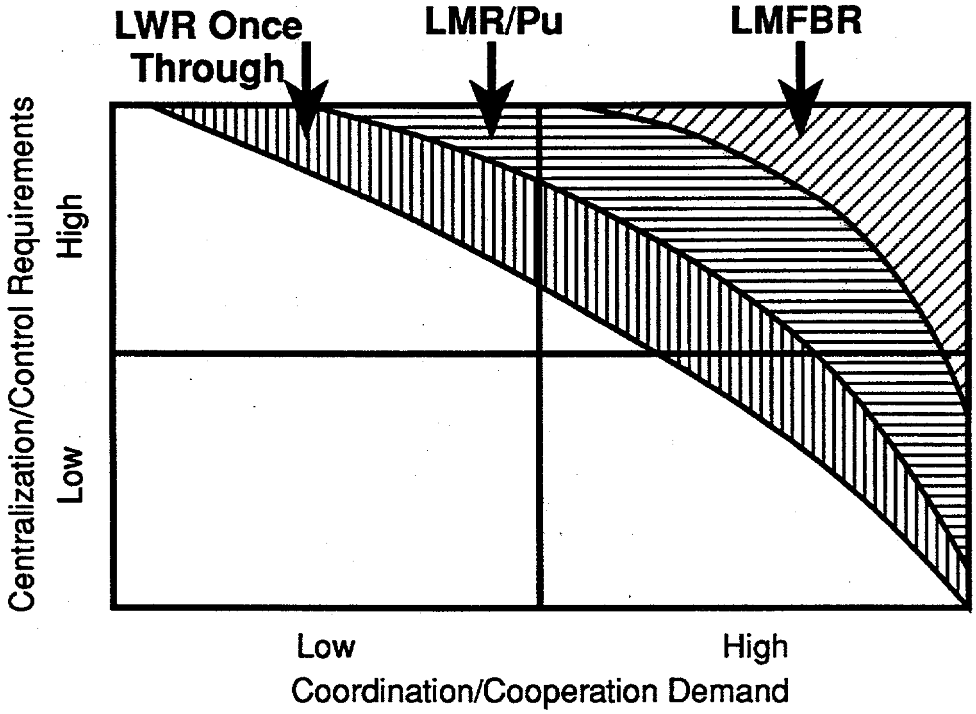
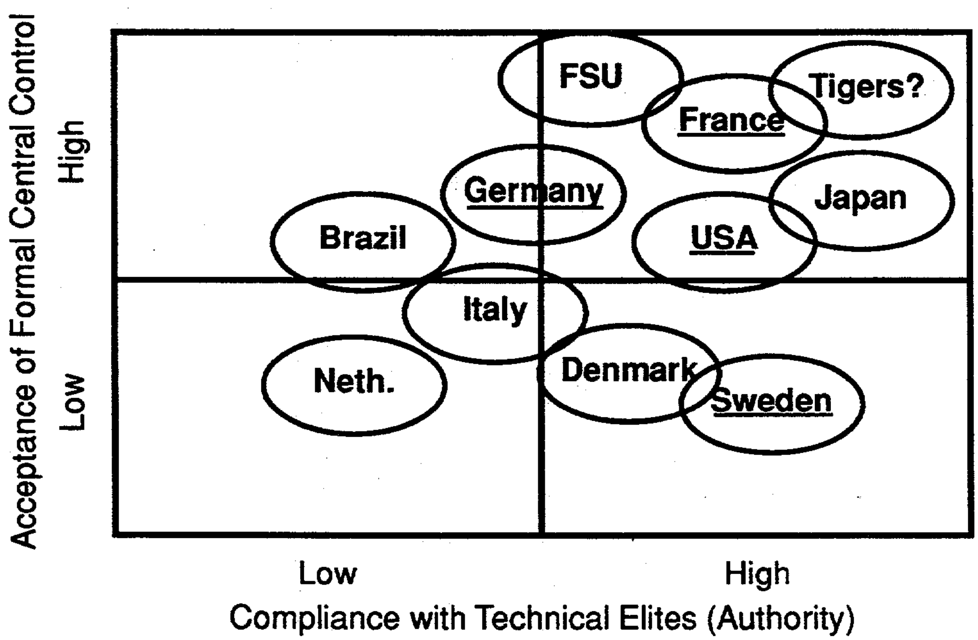


Figure 7.2. Fuel Cycle Demands.



Key: Tigers = S.Korea, Taiwan, etc.
FSU = Former Soviet Union
Underlined are those countries analyzed in (Rochlin, 1994)

Figure 7.3. National Techno-Cultures.

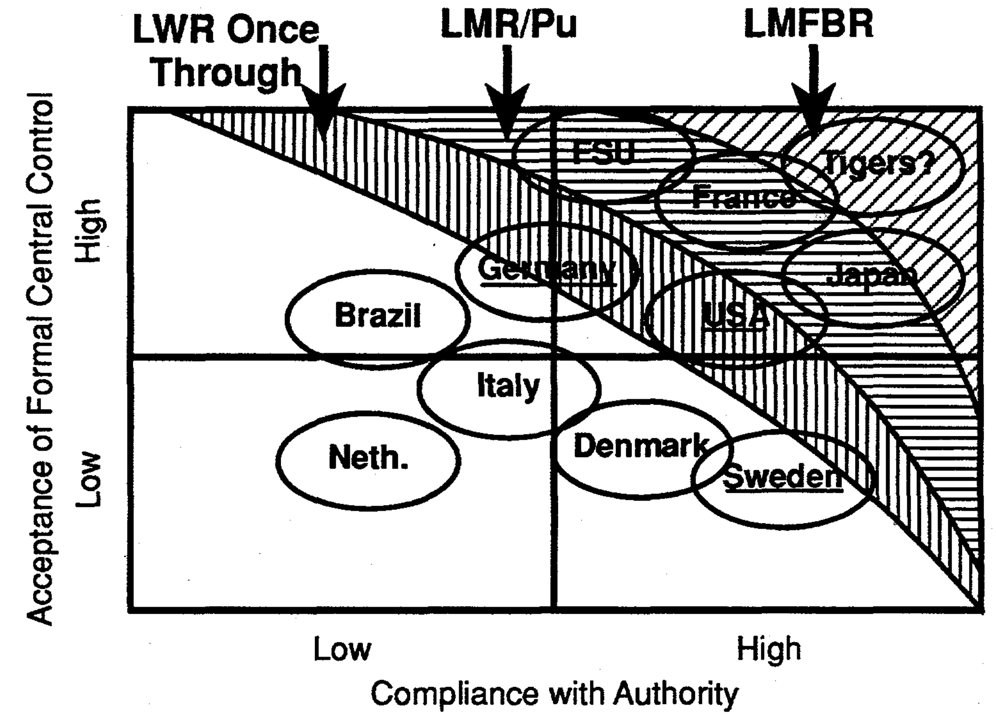


Figure 7.4. Composite Diagram.

to take into account the technical nature of the matter under discussion (large-scale technical systems). The countries underlined are those I have analyzed in some detail elsewhere (Rochlin, 1994; Rochlin and Suchard, 1994). The other countries have been located by pure assertion, based largely on discussion with other researchers sympathetic to the attempt.

Finally, Figure 7.4 superimposes the two previous diagrams, repeating in diagrammatic form my argument that the case of France can best be understood by considering her success to have resulted as much or more from compatibility of the industry with its underlying cultural setting as from the technical, economic, or political ingenuity displayed by the French industry or its supporters.

This diagram is meant to be descriptive and indicative rather than predictive or analytic. It should not be taken as an attempt to substitute for the in-depth socio-cultural analysis that would be required to study each and every case. In all probability, the most reliable aspect is the relative positioning of the various cases.

Even as a heuristic, the diagram suffers from two potentially major shortcomings. First, very little critical field work on the techno-culture has been done. Social studies of nuclear power have tended to focus on accidents or crises and the response and reaction to them, rather than normal operations (Hohenemser and Goble, 1990; Kasperson, 1987; Medvedev, 1991; Perrow, 1984; Sills, et al., 1982). Most of the rest have tended to be studies of oppositional social movements rather than general cultural norms (Jasper, 1990; Joppke, 1993; Nelkin and Pollak, 1982; Touraine, et al., 1983). Second, it is a snapshot taken perhaps in the mid-to-late 1970s, when the social and political commitments to the present state of nuclear power in the several countries were made, more of a social regression than a projection.

But even a regression adjusted to fit historical data can be used to say something meaningful about possible nuclear futures. As has been documented by theoretical and empirical studies in other areas, the social and cultural milieu of American and European countries (including most of those with an existing nuclear industry) has been changing over the past few years. As Prof. Hughes noted in his comments, nuclear power as a technology was the epitome of the technocratic, techno-modern society of the 1950s and 1960s in which it was created and commercialized. At that time, the U.S. was the exemplar of what Balogh (1991) has characterized as the "proministrative" state (for professional plus administrative). In his view, the development of nuclear power is a paradigm of how professionals, scientists and engineers became administrators for the purpose of promoting a huge scientific-technical-industrial enterprise.

This framework clearly describes France and Germany as well as the U.S., particularly in the critical developmental years of the 1960s. Between the 1950s and the 1970s, France did not change much. But the United States moved from a location much closer to where I have now put France towards the indicated position that it now holds in the 1970s. And Sweden and Germany also moved towards the left and down in the diagram, away from centralized control and ready social compliance. If these trends, continue and broaden, further use of the technologies associated with the historical fuel cycles will become increasingly difficult. Moreover, France has begun to move away from technocracy and centralization in recent years (which is bound to create increasing trouble for the Super-Phenix program), and there are some signs that even Japan may now be moving, away from the very high degree of "groupness" and social acceptance that many observers have long taken as their cultural norm (Fujita, et al., 1992; Lincoln and Kalleberg, 1990; Schoenbaum and Ainley, 1988).

CONCLUSION

There are a number of other observations deriving from cultural analysis that are similar to those given above that have some bearing on other aspects of the discussions we have had over the last two days. First, arguments about whether small is beautiful or large is gorgeous can be seen as tensions between defining terms in cultural opposition. They cannot be resolved in debate. What does matter is whether smaller reactors in a simpler fuel cycle will be more compatible with the direction in which modern industrial culture now seems to be moving than larger ones in more complex cycles. Based upon my analysis, I think so. And I believe that Prof. Todreas has come to similar conclusions from within his own perspective.

Second, arguments for simpler, safer reactors will probably not be very persuasive if they are embedded in a range of fuel cycle activities that continue the historical trend towards ever more inflexible and complex nuclear "technology." In particular, I remain convinced that the use of plutonium even as mixed-oxide fuel will be perceived by the public as raising the social stakes, as outlined in the figures. And, yes, this does greatly complicate the desire of many to consume the excess plutonium created during the Cold War by the United States and the former Soviet Union.

Here we have the makings of a very real dilemma. Many who have been opposed to the use of plutonium as a commercial fuel even in the nuclear-weapons states in the past have now come around to the belief that disposal of the plutonium stockpiles should be the dominant concern, even if it requires a government subsidy to make up the excess costs. What the general public, or even the technically aware critical groups think of this, is not known. Indeed, as far as I know it is not even being asked. Prof. Socolow has voiced his concern that only the "nuclear professionals" fail to understand public concern that arises from perceptions of the civil-military link. But even the aware public may not understand how important an issue the weapons plutonium is. If my analysis is even roughly correct, any attempt to modify the civilian cycle to accommodate plutonium fuels, even for the sake of destroying the plutonium, will move it further to the upper right, raising rather than lowering the stridency of the public debate. If the issue is as important as some think it, the relevant governments will have to be prepared to spend some considerable amount of political as well as economic capital to make it happen.

Even more disturbing is the continuing argument that the ultimate goals should be an LMR breeder cycle (and I wonder why the term LMFBR seems to have fallen into disuse), which may be the single most socially and politically demanding large scale technical system yet devised. Even with smaller and safer reactors, the fuel cycle that is envisioned will be far more complex, and require far more control, than the present one. Profs. Golay and Todreas are not alone in the nuclear engineering community in their deep-seated belief that only a breeding fuel cycle makes sense in the long run. From a purely technical perspective, they may even be correct. Yet, at times, the devotion of the nuclear profession to the breeder reactor seems to transcend immediate technical or economic logic, as if it were something of a test of conformance to the dominant techno-ideology. That is a very real danger. Every breeder cycle I have seen analyzed to date involves a huge commitment to centralized control and a set of demands upon public and political bodies; the sincerity of their reaction to that should not be neglected or minimized.

Third, as has already been pointed out several times in this conference, it may be a serious error to treat such outstanding unresolved problems as building smaller and more cost-effective reactors, or inherently safer ones, or more modern and efficient ones, or even securing plutonium or managing nuclear wastes, as if they were separable from other aspects of nuclear power. If present trends hold, there will not be a future for nuclear generation of commercial electricity at all in the near future unless the cycle of social and political activities can be made less centralized and authoritarian, and less demanding of social compliance and cooperation to operate.

As Mason Willrich has pointed out, the utility industry is also in the throes of cultural change. Nuclear power as we know it is most compatible with a model of American electrical utilities that is rapidly becoming outdated. The social agenda I have described is not all that different from what the utilities would like to see as a prelude to their re-entering the nuclear power business. It is not just a matter of safer, cheaper, and more efficient reactors, but also of entire designs for the industry that use facilities that are smaller, simpler to build and operate, and less demanding of regulatory oversight and other forms of centralized and bureaucratic control. If the engineering community could come up with advanced designs that satisfy the latter criteria, there might even be a chance of getting through the interim without losing the critical skills and experience that would be needed to keep the nuclear option alive into the next century.

The premises upon which Prof. Todreas' analysis are based are also not dissimilar. Having a nuclear future requires first a continuing present and secondly a bridge across to future designs that will require at least a generation to get out of engineering and into the design phase. It is even possible that the envisioned future will be run on the breeding fuel cycle that has been the ultimate goal of the nuclear community since the beginning of the commercial reactor program. To accomplish this, he proposes a series of goals and objectives based on advanced light-water designs that meet several quite sensible engineering criteria. But simply meeting technical, or even economic criteria be sufficient without also taking social and political criteria equally into account from the beginning of the development phase is not likely to lead to any more success in deployment than is true in the present and near future.

The history of commercial nuclear technology to date is not one that confers much confidence in the ability of the engineering and technical community either to deal even-handedly with options or to give appropriate weight to social and political constraints as a priori criteria to meet rather than a posteriori critiques to be combatted. That approach did work to some extent during the era when the public was more receptive to engineering initiatives, less critical of technical elites, and more accepting of technological and social formations that involved considerable governmental involvement in design, support, regulation, and even operation. If the trend toward a more fluid, less accepting, and very much post-techno-modern society continues, there may well continue to be some fairly unpleasant surprises for the industry unless it learns to become more sensitive to the cultural milieu in which it operates.

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WHAT SHOULD OUR FUTURE NUCLEAR ENERGY STRATEGY BE?

DISCUSSION

U.S. Nuclear Power Industry Professional:

I was struck by the thought that there is no one in this room that is in a position to buy a nuclear power plant. That is an interesting observation. This is an academic Conference. The future of nuclear power and the technology with the people supporting it is going to be determined by those who will buy power plants. In considering the future, the views of this group must be given special attention.

U.S. Nuclear Power Industry Professional:

Whenever the market is going to arise for the simplified economical reactors, the prospect is that in the near term, what sales are going to occur in the international market certainly will be from developed evolutionary designs.

I would like to refer again to the comment that I made yesterday about the fact that at the time the *Boston Globe* did not know that Yankee Rowe had been operating in the Commonwealth of Massachusetts for 12 years, and it was being operated by only 65 people. There is a tremendous amount of information in the history of the nuclear enterprise, even if only in this country, concerning the proliferation of regulations that have governed the power plant designer.

My comments are intended to apply independent of the fuel cycle. I think it applies to all fuel cycles that there is a tremendous lesson to be learned about the effects of each additional level of regulation that has been imposed. I am completely convinced that plants could be built using one half the hardware, and be safer because they would be simpler and easier for the operators to understand. I am not against using more controls for new plants in general. However, I believe that the human operating a reactor should always have the overriding power.

I submit there is a great opportunity for university research projects to look at the proliferation of regulations that has taken place since the time when the first plant was built up to that of the last plants that went into service just a few years ago. I just believe that if only a few years of effort were taken to analyze the proliferation of regulations, the very exacting requirements that have been imposed—particularly in mechanical and electrical areas—that it would reveal the need for simplicity and elimination of hardware. Then we would get much closer to the simple and economical plant of the future.

International Energy Researcher:

I will discuss the future of nuclear power from a Japanese perspective. First point: The United States passive light water reactor (LWR) is a great advancement compared with the conventional 600 MW plant. But for Japan, our utilities are interested in larger plants, so we are looking for future improvements in the evolutionary nuclear reactors.

The second point that I wish to raise concerns economic competitiveness. It is very important. We are living in a free market economy. The general public will not wish to pay for high cost nuclear electricity if it can be generated by any other means at lower cost. So, economical competitiveness is very important. That is the reason why we in Japan are going to continue to follow the original evolutionary developmental path.

Fast breeder reactors offer economical and safety advantages, although not in all areas. So we are looking at the future of LWRs with efforts to reduce labor needs, especially skilled labor, in the maintenance area. Concerning technology, we are studying advanced digital control.

As for the fast liquid metal reactors, much will be decided in the coming year. Monju is going well. We are discussing the design for the next demonstration fast liquid metal reactors.

We are particularly concerned to design them so that they are not so expensive. At the moment we are concerned about whether they can be competitive with light water reactors.

I want to raise another point concerning the use of fossil fuel technology. They are becoming more economical. The point is that the nuclear plants must also improve the thermal efficiency. Fossil-fueled power plants have been operating at supercritical pressure for more than 55 years, and 25 years in Japan. This has improved efficiency and simplification. The other point to note is that of the possibilities for power conversion system simplification using supercritical steam. With superheating we do not need steam dryers and separators because there is not change of phase. So, if we could develop a supercritical PWR, the efficiency change could be very large, with a relative increase of 25%. This system is a direction for future improvements.

Another point concerns the breeder reactor, which promises to be a great advantage for us in Japan, since we do not have energy resources. To have a breeder we need to reduce our problems, our plutonium mobility. So, we have to keep the option of reprocessing and converting plutonium into mixed oxide (MOX) fuel. Most of the plutonium can be burned in LWRs, and this scheme can be economical. If you say that this is too expensive, it is not right—it is wrong. We have studied this for a over twenty years.

However, the solar energy biomass is expensive because it requires a large area. So, while solar energy can be applied broadly in Japan, but it is obvious that we do not want to use it. Rather, it might be a supplement to our major electricity sources like the fossil fired plants and the nuclear plants in Japan, and probably in some other countries.

I should point out that, even if people use the renewables a lot and were successful, there would still be environmental problems. Surely some environmentalists ignore this. This is a very bad thing. Also, some wastes arise from environmental programs, from solar biomass fuel, or any other. You have to look also at the waste problems. We have two solutions: one is treatment as sewage; the other is disposing of waste deep underground. That is a feasible solution. Solutions exist, so if you kill the nuclear power option, you will depend on fossil fuel energy because it is the most economical. You will generate waste and pollute your environment and the global environment by so much use of fossil fuels. This is a very important point. So, in order to protect the environment, it is the responsibility of the advanced countries to develop and deploy advanced nuclear plants.

International Nuclear Power Industry Professional:

Taiwan power is going to build its fourth nuclear power station consisting of two identical units. Taipower has proceeded with a design optimization study program until early December of this year, when we will submit our proposal. This design incorporates the operating experience of Taipower's existing three plants [of two units, each] and also the experience gathered from the nuclear programs worldwide. We use proven technology whenever possible. We adapted to minimize the investment risks, such as is done with the evolutionary advanced light water reactor (ALWR) which has been selected for use. I would like to point out some of the major requirements of the evolutionary ALWR. We have achieved major improvements in core damage frequency, as is demonstrated by the PRA ($10^{-5}Ry^{-1}$ for core damage and $10^{-6}Ry^{-1}$ for large offsite release). We expect to reduce the occupational radiation dose exposure (<100 Person-Rem Ry^{-1}).

We also have licensing requirements that are different from some in the United States. With the first one we use a double containment to minimize the low population zone, and we use a high seismic design. Our low level radioactive waste will be dealt-with by advanced compacting system on-site storage at our on-site storage facility. The spent fuel storage capacity will be enough to accept forty years' worth of the low-level radioactive waste production. On our plant site, the high-level waste capacity will be enough for forty years also. From the overall point of view, our new project will meet the sixty years life and low reactor vessel fluence requirements set forth in the evolutionary EPRI Utility Requirements Document (URD). It will also take into account our domestic experience, and will satisfy our environmental protection requirements. The management is eager for improvement of the quality of the design, with reduction of impact to the environment, to be a good neighbor, and with the reduction in construction cost. We will make every effort to meet that goal.

Dr. Robert Williams (Princeton University):

I would like to make two comments: one is on Prof. Hansen's comment on my presentation yesterday, and the second comment is a collective one dealing with the talks we have heard this afternoon by both Prof. Todreas and Prof. Rochlin, and also the comment concerning nuclear energy in Japan.

The first comment relates to the issue of subsidies for energy R&D. I was remiss in not responding to the comment on my paper yesterday, but I would just like to clarify the record in this regard. I ended my table with data for 1991 because I wanted to show world totals. The totals for all of the OECD countries and other data are not yet available for years after 1991.

There has been a 70–80% increase in the total U.S. solar R&D budget between 1991 until 1994. The FY 1994 number is about $240 million for all solar R&D. The point that I was wanting to stress, however, was that of the historical embedded R&D cost. This cost is exclusive of all market stimulation subsidies. For photovoltaics it is less than $2 billion; for all of solar, it is $7 billion; for nuclear, it is $56 billion. For comparison, it is $25 billion for fossil fuels. Those are data stated in 1992 dollars and their entire historical R&D cost in those contexts. I often hesitate to try to quantify the numbers associated with market subsidies other than R&D because this tends to be, and can very easily become, a liars' contest, because it depends very sensitively on how you do these calculations. If I do not perform the calculations myself, I do not usually like to cite them. However, I would like to call your attention to a major study that was done by the Alliance for Safe Energy, that was published this spring. The authors looked in some detail at all of the subsidies to the energy industry: both fossil fuel, renewables, nuclear, induced conservation, and others. These included R&D plus whole market subsidies. The way in which they defined the subsidies was in terms of their value to the users, or the market value of the subsidies. The total for all of the energy industry in 1994, according to this report, is $36 billion, of which $21 billion was for fossil fuels, $11 billion was for nuclear, and the rest went to all the other sources.

My other comment is about the presentation that we heard this afternoon. I think that it is very important in thinking about new nuclear technologies, to consider the long term future as to where this technology is going to be if it is completely successful in penetrating the market. We are trying to do this in the renewable energy area. As I indicated to you I think that if you want to consider biomass seriously in the global situation you want to try to understand in some detail what it means to have 400 million hectares of biomass plantation in the world. How can you do that in environmentally acceptable way, if in fact you can? It is very important to do such an analysis before we launch a major R&D commitment aimed at establishing new industries of that type. Likewise, it is incumbent upon the nuclear community to think about a world in which you have something like 5000 GW of nuclear power at some indefinite date in the future.

If you do not think about that kind of a world, and plan for it now, you are going to be in real trouble. It has been very clear in the course of the last couple of days that it is very difficult in the nuclear area to make substantial changes in the technology. But, if you are going to introduce a new technology it ought to be a technology that you would be comfortable with in a world with 5000 GW. This is a world in which characters like Saddam Hussain and Moammar Khadafy are going to have equal access to this kind of technology.

I was a little bit disturbed by Gene Rochlin's suggestion in his talk that maybe we should not separate the military atom from the peaceful atom to the extent that he thought that we previously should. I would submit that it is important not to be blindsided by the immediate requirements of dealing with, for example, the nuclear weapons—usable material in the former Soviet Union with regard to formulating a long term technological solution. Rather, you should be thinking about the world with 5000 GW in it. I submit that in that world, if you do not make the civilian atom absolutely distinct from the military atom, the nuclear industry is going to be in real trouble with regard to its future nuclear technological options.

I think that it may well be true that because of the greenhouse warming problem, nuclear power may get a second chance. But, if there is some major weapons material diversion incident in the world which can at least be plausibly linked to nuclear power, it is going to very difficult, I think, for nuclear power to get a third chance.

Prof. Michael Golay (MIT):

Thank you. I think I would like to connect these remarks concerning the implications of the vastly expanded nuclear economy and ask Mr. Kim who comes from a country with the most rapidly growing nuclear economy to also make some remarks regarding how the future looks there.

Mr. Si-Hwan Kim (Korea Atomic Energy Research Institute):

I would like to just describe our progress in development of the next generation PWRs in Korea. As of today, nine nuclear power plants are in operation in Korea, and seven nuclear power plants are under construction. Furthermore, seven to eleven more nuclear power plants are required by the end of the year 2006. We will probably introduce a next generation of PWRs. Last year a program for the development of the next generation was established by Korea Electric Power Company (KEPCO). The budget is about $300 million for over ten years to complete the detailed design. We are planning to introduce next generation reactors in the next century. However, at this moment, the time of starting the next generation PWR is not yet determined. The reactor time and the design features will be decided by the end of next year (1994).

Currently, we can see three candidates to serve as the next generation PWR in Korea. The first one is a 1000-1300 MWe passive class advanced PWR. The second choice will be 600-900 MWe evolutionary PWRs. The third one is an advanced plant with passive safety features.

Also, I would like to describe briefly the nuclear waste storage issue in Korea. In 1989 Korean government established a plan to construct and operate low-level waste and spent fuel storage facility by 1997. However, we are having difficulties with securing a site because of the lack of public acceptance. We have extended the on-site fuel storage duration as an interim measure. The power plants will store spent fuel in the extended space until the year 2002. Now, we continue our efforts to secure the waste disposal site by improving the public acceptance.

Mr. E.C. Brolin (USDOE):

I would first like to thank Prof. Golay and all of the other people who contributed to this Conference—on both sides of the aisle, so to speak. I and others will have to deal with the future of the of the new nuclear power strategy in real time, and we appreciate the thoughts that have been given here. I would like to emphasize for those of you who want to contribute to this debate over the long term, including those in the academic community, that in tight budget times, that is to say now and for the foreseeable future, what will drive us is not so much the technical leadership aspect, but the commercial prospect for new technologies. We will have to make sure that our R&D programs are consistent with what the user needs. The users are represented here by the utilities. We will also be very careful about the other national needs, including making sure that we are compatible with the environmental community. But the academic fraternity will have to accommodate itself to the situation. Thank you.

Prof. Golay:

At this point, I want to end this last session of the Conference. In doing so, I want to summarize some of the main ideas which were expressed. Our last conference made a contribution through drawing attention to the role of trust as a major factor affecting whether nuclear power would go forward. From this Conference, several important ideas have also emerged. Concerning the current impasse over the social acceptance of nuclear power, factors of the power struggle between the different segments of society have been raised. The role of trust, once again, has been emphasized, and the nexus between civilian and military uses of nuclear reactors has come up repeatedly. Exactly, what is the right response to that combination of factors for people involved in nuclear work remains to be debated. But the importance of having some response is clearly implied.

One of the things that has been interesting in this meeting is, as in the Sherlock Holmes detective series, the dog that did not bark. In our last meeting there was great emphasis upon the ways in which different nuclear hardware versions could change public acceptance outcomes, particularly in terms of the safety claims of different reactor concepts. The fact that the merits of different reactor concepts have not been much discussed in this Conference recognizes a new consensus that the nature of reactor technology is not the central question. That is not to say that the nature of the hardware is unimportant, but rather the realization seems to be that there are other questions that have to be answered first in determining the nuclear future.

Another thing which has emerged is that of the effects of the tremendous pressures which utilities find themselves under worldwide. Competition is increasing for everybody, not just here in the United States, but it is affecting utility industries worldwide. We have seen, for example, deregulation of the utility industry in the U.S. We have seen privatization in the United Kingdom. You see it being eminent within Italy; and the same proposal has been raised within France. These moves, surely, will have profound implications for what happens with nuclear technology among other electrical technologies. That future was clearly recognized in the discussions here. Mr. Brolin has also drawn attention to the change in the climate within the public sector and the reducing scope of freedom that one will have, I think, to explore technological innovations with support from the public.

One of the things which emerged in the previous Conference was that, if nuclear power is going to make any kind of reasonable case for a major social role, a role which it does have at the moment, but where there is a question of whether it will continue to do so, has to be considered in context. When we structured this Conference we deliberately made sure that the case for alternative energy technologies would have the opportunity to be stated very clearly. I believe that such a statement has been made. What I got from that discussion was that there are a number of renewable technologies which have shown considerable promise. However, they are still at the stage of showing promise and have not quite reached the stage of maturity where they are practical options that one could employ on a large scale. However, that may change reasonably quickly depending upon future developments.

I alluded previously to the question of nuclear weapons proliferation. One of the things which emerges from the discussions of this Conference is that there are clear technical solutions to consider when we are dealing with proliferation. But, also, there exist large attendant political uncertainties which makes it difficult to choose the best, or even maybe the fourth best option to actually pursue at a very heavy scale. The urgency to pursue something is clear, however.

The suggestion that the problem of trust in dealing with many of the nuclear issues came up and was stated especially provocatively regarding the need to put the nuclear waste disposal and, perhaps the nuclear weapons site remediation tasks in the hands of other agencies, which might be constrained by somewhat less rigid schedules promises, budgets, etc. than is the DOE. I am sure that trust is important in solving these problems. This is true in the U.S. and I expect so elsewhere.

Regarding the future development of nuclear fission technology, we have had stated a vision which basically says do not plan your future in too much detail; allow for the fact that there are fairly broad time horizons over which significant innovations could be achieved. However, you also have got to be realistic and build from the foundations that we have today. We see that thought both in the proposals which Prof. Todreas offered, and also in terms of the ways that the countries in Eastern Asia having expanding economies are actually developing their nuclear sectors.

During the past ten years we have engaged in the somewhat sterile debate over what is the best paper reactor rather than cooperating more in trying to create realistic technological alternatives. The light water reactor has won out in that competition, reflecting the principle that technologies which are more mature tend to do well in competing with technologies that are less mature and more uncertain. What I got from the discussion in this last session was essentially to say let us keep our options open, and make sure that we are working on full menu of problems which experience reveals to be important.

I would say to those leading the nuclear enterprise that what I get from this Conference in general is that if we are to be successful it will be necessary to recognize that nuclear power is an enterprise involving a social, economic and physical elements, probably listed in that order of importance. However, whenever we get too carried away with that kind of thinking, I am also reminded of the engineering solution where the plumbing does not hold water. Physical factors within a problem have a way of rising in importance very fast if not given the proper attention. We have to pose our problems and solutions in ways which will make the solutions practical for the various constituencies of society, all of whom have to say yes if we are to be successful. That means that we have to find ways to both recognize the requirements of all of these constituencies and to make it possible for them to reach the conclusion that what we purpose is both desirable and beneficial. I hope that this Conference has helped us in realizing ways to do that, and also to make it interesting for other people who want to talk with us further about this.

A good sign of a successful meeting is that it ends with the participants wanting more. In fact, with the sessions of this morning I have had that problem; I have had to disappoint some people by not being able to call on them. I want to thank everybody for staying enthusiastic despite these limitations. The fact that the room is still as full as it is at this point in the meeting, I think is a tribute to the interest and enthusiasm that the participants have brought to it. I want to thank you for your ideas and cooperation throughout the meeting. We are now adjourned.

CONFERENCE SUMMARY

Michael W. Golay
Massachusetts Institute of Technology

CONFERENCE SUMMARY

Michael W. Golay

The Second MIT International Conference on the Next Generation of Nuclear Power Technology was held on 25 and 26 October 1993 at the Massachusetts Institute of Technology. The Conference was the second in a series of meetings structured to provide a forum for debate over the future policies for advancement and use of nuclear power within the context of the overall energy economy. It was attended by approximately 80 participants. The attendance was limited to this number in order to permit reasonably orderly discussion of the topic being debated.

The Conference was organized into seven session, where each of the first six sessions addressed a question important to the future of nuclear power, and the final session built upon all of the others, addressing the question "What Should Our Future Nuclear Energy Strategy Be?"

The topics addressed within the Conference include the status and prospects for both the current and future nuclear power technologies, the degree of public acceptance of nuclear power implications of potential diversion of plutonium for civilian nuclear power and what can be done to prevent it, the reasons that nuclear wastes are not being stored permanently and the implications of a continued social impasse block resolution of the fate of existing and future wastes, and the potential future roles for the "alternative" energy technologies. The last topic is especially important, as many objections to the use of nuclear power are justified by the assertion that the alternative technologies can be made sufficiently attractive to eliminate the need for conventional energy technologies, including nuclear ones.

Each session of the Conference was organized around a keynote paper and a respondent paper, each of which addressed the question which was the topic of the session. Following these two papers, a free-form discussion of the session's topic ensued. The papers and discussion are presented in these proceedings. In order to ensure an uninhibited debate, the participants are not identified except when they identified themselves in the discussion, or were serving as paper authors.

The participants were primarily drawn from the following four groups:

- United States professionals in the nuclear power enterprise,
- United States critics of the nuclear power enterprise,
- United States students of society and technology, and
- International professionals in the nuclear power enterprise.

The purpose of inviting the meeting's participants from among these groups was to stimulate a rich mix of ideas from a diverse, informed set of experts.

Several important factors which are likely to affect the future of nuclear power were identified and discussed during the Conference. These include the following: trust of individuals and organization, fear of nuclear weapons, the potential for diversion of weapons materials, the inability to dispose of nuclear wastes, the relative economic competitiveness of the various energy technologies, fear of nuclear accidents, opportunities provided by the United States' political system for blockage of nuclear power project by small but determined minorities, concerns about potential global warming, concerns about the environmental effects of the different energy technologies, inefficiency and inconsistency in the systems for safety and economic regulation of nuclear power plants, current public indifference to how energy needs will be met, the absence of a strong sense among the public that nuclear power provides important social benefits, and deficiencies and strengths of the nuclear power technologies themselves.

It is clear that the interaction of these different factors is complex and difficult to understand. It was suggested in the Conference that the proponents of nuclear power have sometimes been less successful than possible because they have not sufficiently alert to the importance of some of these factors, particularly trust, in affecting the decision-making environment in which they work.

It was also notable that consensus was apparent that the differences between passively safe and evolutionary versions of nuclear power technologies are likely to be less important than the factors mentioned above in affecting the future uses of nuclear power. This was the greatest change between the First and Second Conferences in the series.

It became apparent that some of the Conference's participants hold strongly different beliefs concerning facts, values and goals for the future with regard to energy, as well as for the nature of society in general. Consequently, complete consensus did not emerge among the participants. However, for most participants there appeared to be a degree of agreement that nuclear power should play a role among energy technology options to be used in the future. However, this use would be governed by strong requirements that it be used safely, in a way which protects the environment and does not lead to nuclear weapons proliferation. There also appeared to be consensus that the future of nuclear power would depend upon its economic competitiveness. In the United States the ability to compete is more questionable than elsewhere in the world, and the near-term prospects of the technology are cloudy. Similarly, consensus was apparent that the promise of the "alternative" energy technologies remains unproven, but worth pursuing. So, the "alternative" technologies continue as hypothetical possibilities rather than proven feasible, practical options. It was unclear whether use of these technologies would actually be welcomed throughout society, should they live up to the promise.

So, the prospect remains that the future of nuclear power outside of rapidly growing Asian countries will be one of stasis, tending toward decay. A contribution of the Conference has been to illuminate the reasons for this outcome, and to identify some of the factors which could change it. A second contribution of the Conference was to make the ideas expressed available to the reader for the benefits which they may provide.

APPENDICES

A. LIST OF ATTENDEES

B. LIST OF ABBREVIATIONS

C. IMPLEMENTATION OF THE SAFETY GOALS, SECY-89-102

APPENDIX A

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APPENDIX B

LIST OF ABBREVIATIONS

AID – Agency for International Development
ALMR – Advanced Light Water Reactor
ANL – Argonne National Laboratory
ATR – Advanced Test Reactor
AVLIS – Atomic Vapor Laser Isotope Separation
BIG/GT – Biomass-Integrated Gasifier/Gas Turbine
BPEV – Battery Powered Electric Vehicle
BWR – Boiling Water Reactor
CAES – Compressed Air Energy Storage
CIS – Confederacy of Independent States
CRIEPI – (Japanese) Central Research Institute of Electric Power Industry
DOE – (United States) Department of Energy
DWPF – Defense Waste Processing Facility
DSM – Demand Side Management
EBR-2 – Experimental Breeder Reactor-2
EM – Envrionmental Management
EPA – Environmental Protection Agency *also* Energy Policy Act of 1992
EPR – European Pressurized (Water) Reactor
EPRI – Electric Power Research Institute
EWG – Exempt Wholesale Generator
FCV – Fuel Cell Vehicle
FFTF – Fast Flux Test Facility
GCR – Gas-Cooled Reactor
HEU – Highly Enriched Uranium
HLW – High-Level [Radioactive] Waste
HTGR – High Temperature Gas-cooled Reactor
IAEA – Internatinal Atomic Engergy Agency
ICEV – Internal Combusion Engine Vehicle
IFR – Integral Fast Reactor
IMS – Information Management System
INPO – Institute for Nuclear Power Operations
IPCC – Intergovernmental Panel on Climate Change
IPP – Independent Power Producer
KEPCO – Korea Electric Power Company
LDV – Light Duty Vehicle
LEU – Low Enrichment Uranium
LMFBR – Liquid Metal Fast Breeder Reactor
LMR – Liquid Metal Reactor
LWR – Light Water Reactor
MAGNOX – (United Kingdom) Natural Uranium Graphite-Moderated Magnesium-Clad Reactor
MHTGR – Modular High Temperature Gas-cooled Reactor
MIT – Massachusetts Institute of Technology
MOX – Mixed Oxide
MRS – Monitored Restrivable Storage
NAS – National Academy of Sciences
NIMBY – Not in My Backyard
NPT – Nuclear Non-Proliferation Treaty
NRC – (United States) Nuclear Regulatory Commission
NREL – National Renewable Energy Laboratory
NWPA – Nuclear Waste Policy Act of 1982
NWPAA – Nuclear Waste Policy Amendments Act of 1987
O&M – Operations and Maintenance
OCRWM – Office of Civilian Radioactive Waste Management
OECD – Organization for Economic Cooperation and Development
PRA – Probabilistic Risk Assessment
PUC – Pubic Utility Commission
PURPA – Public Utility Regulatory Policies Act of 1978
PWR – Pressurized Water Reactor
QF – Qualifying Facility
R&D – Research and Development
RET – Renewable Energy Technology
RIGES – Renewables-Intensive Global Energy Scenario
RBMK – Soviet Graphite-Moderated, Boiling Water-Cooled, Pressure Tube Reactor
RSWG – Response Strategies Working Group
SBWR – Simplified Boiling Water Reactor
SDS – Students for a Democratic Society
SEAB – Secretary of Energy Advisory Board
SSC – Super-conducting Super Collider
SUTIL – Sustainable UTILity

LIST OF ABBREVIATIONS (continued)

- TMI – Three Mile Island
- UNCED – United Nations Solar Energy Group
- URD – Utility Requirements Document
- VSWT – Variable Speed Wind Turbine
- VVER – Soviet Version of the Pressurized Water Reactor
- WANO – World Association of Nuclear Operators
- WIPP – Waste Isolation Pilot Plant

APPENDIX C

IMPLEMENTATION OF THE SAFETY GOALS, SECY-89-102

This Appendix contains the most recent statement of the NRC's Safety Goals. The formulation of the goals has changed somewhat since their initial promulgation in 1983, as they have been refined and problems of their practical application have been considered. This process appears likely to continue. Thus, the version presented here might be considered as an interim formulation.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555

OFFICE OF THE SECRETARY

June 15, 1990

MEMORANDUM FOR: James M. Taylor, Executive Director for Operations

FROM: Samuel J. Chilk, Secretary

SUBJECT: SECY-89-102 - IMPLEMENTATION OF THE SAFETY GOALS

The Commission's objective in publishing the Safety Goal Policy Statement was to define an acceptable level of radiological risk from nuclear power plant operation. The Commission also believed that by establishing a level of safety considered to be safe enough, public understanding of regulatory criteria and public confidence in the safety of operating plants would be enhanced. In formulating the policy, the Commission indicated that it believed that current regulatory practice ensured compliance with the basic statutory standard of adequate protection; but the Commission also believed that current practices could be improved to provide a better means for testing the adequacy of current requirements and the possible need for additional requirements. In establishing this policy, the Commission adopted two qualitative safety goals that are supported by two quantitative health effects objectives for use in the regulatory decision making process. The Commission reaffirms its endorsement of these earlier initiatives. The Commission has approved the following actions relating to the Safety Goal Policy Statement:

1) Probabilistic risk assessment (PRA) is used as a tool to provide measures of plant performance and overall risk to the public. Insights can be drawn from this information to evaluate the consistency of regulations with the safety goals and, to identify possible changes in the regulations that make them more consistent with the safety goals. The result of the several PRA level calculations (i.e., core damage probability, source terms, consequence estimates), as well as the results of the various internal steps within each level, can be compared with certain specific regulatory requirements. This has resulted in the suggestion that the Safety Goals and health objectives be partitioned into further subsidiary objectives. While the Commission believes

NOTE: THIS SRM AND THE SUBJECT SECY PAPER WILL BE MADE PUBLICLY AVAILABLE 10 WORKING DAYS AFTER ISSUANCE OF THE SRM.

that such "partitioned" objectives can be useful in making regulatory decisions and improving regulatory practices, it does not believe it is necessary to specifically incorporate the partitioned objectives into the Safety Goal Policy Statement.

2) In the Safety Goal Policy Statement, the Commission proposed for further staff examination a guideline for general plant performance that the overall mean frequency of a large release of radioactive materials to the environment from a reactor accident should be less than 1 in 1,000,000 per year of reactor operation. The examination of this proposed guideline by the staff has resulted in a conclusion that specifying this frequency as an overall mean value is inherently more conservative than either of the quantitative health effects objectives. However, this more conservative result is within an order of magnitude of the Commission's health objectives and provides a simple goal which has generally been accepted. The Commission believes that the basic concept of a plant performance objective that focuses on accidental releases from the plant and eliminates site characteristics, as suggested by the ACRS, is appropriate. The staff should evaluate and advise the Commission whether such an objective can be developed and how it would be useful. In conducting this evaluation, the staff should formulate a new definition for large release and supporting rationale consistent with this approach.

(EDO) (SECY Suspense: 9/28/90)

3) The staff, in developing and reviewing regulations and regulatory practices, should routinely consider the safety goals. To achieve this objective, the staff should establish a formal mechanism including documentation for ensuring that future regulatory initiatives are evaluated for conformity with the safety goal. (Recognizing that the state of knowledge is such that the degree to which regulatory issues can be related to the safety goals will vary considerably, the staff's consideration of the safety goals could range anywhere from quantitative risk comparisons involving the safety goals themselves to a deterministic judgment that, in light of the safety goals and available knowledge (or lack thereof), a given issue does or does not warrant a change to the regulations or regulatory practices.)

(EDO) (SECY Suspense: 11/30/90)

4) Implementation of the safety goal may require development and use of "partitioned" objectives. In

general, the additional objectives should not introduce additional conservatisms. The staff should bring its recommendations on the use of each such subsidiary objective to the Commission in the context of the specific issue for which it would be useful and appropriate, and explain its compatibility with the safety goals. Based upon the NRC's review of a sample of plant PRAs, it appears that these plants not only meet the quantitative health effects objectives but exceed them. This may or may not reflect excessive conservatism in regulations. While there have been improvements in PRA techniques, uncertainties in the summary results are still such that quantitative PRA objectives should not be used as licensing standards or requirements.

The Commission believes that the safety goal objectives should be applied to all designs, independent of the size of containment or character of a particular design approach to the release mitigation function. Accordingly, for the purpose of implementation, the staff may establish subsidiary quantitative core damage frequency and containment performance objectives through partitioning of the Large Release Guideline. These subsidiary objectives should anchor, or provide guidance on "minimum" acceptance criteria for prevention (e.g. core damage frequency) and mitigation (e.g. containment or confinement performance) and thus assure an appropriate multi-barrier defense-in-depth balance in design. Such subsidiary objectives should be consistent with the large release guideline, and not introduce additional conservatism so as to create a de facto new Large Release Guideline.

A core damage probability of less than 1 in 10,000 per year of reactor operation appears to be a very useful subsidiary benchmark in making judgements about that portion of our regulations which are directed toward accident prevention.

Containment performance objectives for evolutionary and advanced designs should be submitted to the Commission for approval, together with a justification for the recommended approach. In developing recommendations the staff should assure that:

a) The CCFP objective is not so conservative as to constitute a de facto new "Large Release Guideline."

b) Establishment of a CCFP should be approached in such a manner that additional emphasis on prevention is not discouraged. In this regard, staff should develop appropriate guidance for establishing CCFPs to address this concern and provide a uniform methodology for implementing such an approach.

c) Recognizing that it is entirely possible that a deterministically-established containment performance objective could achieve the same overall objective as a CCFP, staff should be prepared to review the merits of such an approach (if proposed) and, if workable, accept such an approach as an alternative to a CCFP.

The Commission has no objection to the use of a 10^{-1} CCFP objective for the evolutionary design, as applied in the manner described above.

Within a particular design class (e.g., LWRs, LMRs, HTGRs) the same subsidiary objectives should apply to both current as well as future designs. A specific subsidiary objective might differ from one design class to another design class to account for different mitigating concepts (e.g. confinement instead of containment). However, the Large Release Guideline relates to all current as well as future designs.

These partitioned objectives are not to be imposed as requirements themselves but may be useful as a basis for regulatory guidance.

5) It is important to note that the Commission has made it clear in the advanced plant and severe accident policy statements that it expects that advanced designs will reflect the benefits of significant research and development work and experience gained in operating the many power and development reactors, and that vendors will achieve a higher standard of severe accident safety performance than their prior designs. The industry's goal of designing future reactors to a core damage probability of less than 1 in 100,000 per year of reactor operation (EPRI for ALWRs and GE for the ABWR) is evidence of industry's commitment to NRC's severe accident policy. The Commission applauds such a commitment. However, the NRC will not use industry's design objectives as the basis to establish new requirements.

6) In order to enhance our regulatory process for the current generations of plants, the Commission believes the staff should strive for a risk level consistent with the safety goals in developing or revising regulations. In developing and applying such new requirements to existing plants, the Backfit Rule should apply.

7) The Commission supports the use of averted on-site costs as an offset against other licensee costs (and not as a benefit) in cost-benefit analyses.

8) Both the staff and ACRS agree that the safety goal objectives and other relevant objectives should be used to identify possible changes in the regulations applicable to nuclear power plants; however, the task of undertaking a total review of the whole body of applicable regulations and regulatory practices appears to be a massive, resource intensive effort. The staff should describe a plan, with specific detail, for assessing the consistency of our regulations with the safety goals and for identifying and possibly eliminating unnecessary requirements, and modifying requirements that may be inadequate. This may fold in current work to review regulations and eliminate unnecessary requirements, and plans to use IPE-PRA information to make comparisons of current regulations with safety goal objectives. The staff should consider whether a trial case of limited scope may be a useful way to proceed with this request.

(EDO) (SECY SUSPENSE: 12/91)

9) In stating that quantitative objectives can be useful in making regulatory decisions to address safety issues, the Commission recognizes the uncertainties associated with the numerical results of PRA. Some issues (e.g., human performance) also do not readily lend themselves to quantitative comparisons.

Therefore, the staff in applying the criteria provided in 10 CFR Part 52 may conclude that additional requirements are needed based on experience with prior designs in order to provide substantial assurance that future designs will meet the level of safety provided in the Safety Goal Policy Statement. The staff should elevate such safety issues to the Commission for consideration and should not be constrained from proposing new requirements where benefits cannot be quantified in terms of risk.

10) The Commission believes that "adequate protection" is a case by case finding based on evaluating a plant and site combination and considering the body of our regulations. Safety goals are to be used in a more generic sense and not to make specific licensing decisions. It is not necessary to create a generic definition of adequate protection, nor is it necessary to amend the Safety Goal Policy Statement in order to provide a direct relationship between the safety goals and the concept of adequate protection.

11) The Commission agrees that it must not depart from or be seen as obscuring the arguments made in court defending the Backfit Rule.

These arguments clearly established that there is a level of safety that is referred to as "adequate protection". This is the level that must be assured without regard to cost and, thus, without invoking the procedures required by the Backfit Rule. 1/ Beyond adequate protection, if the NRC decides to consider enhancements to safety, costs must be considered, and the cost-benefit analysis required by the Backfit Rule must be performed. The Safety Goals, on the other hand, are silent on the issue of cost but do provide a definition of "how safe is safe enough" that should be seen as guidance on how far to go when proposing safety enhancements, including those to be considered under the Backfit Rule.

12) The term "credible" is used in Part 100 and has in some instances been given a probabilistic interpretation or definition by the staff which is more stringent than the Large Release Guideline. This lack of uniformity should be addressed by the staff in conjunction with the staff's efforts on siting.

13) All Commissioners agree that how well a plant is operated is a vital component of plant safety. In order to improve communication to the public, ACRS has recommended that this fact be given more prominence in the Safety Goal Policy Statement as a major element

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1/ On a related point, the presumption is that compliance with our regulations provides adequate protection. The converse, however, is not true, i.e. adequate protection does not necessarily require compliance with the body of our regulations. The Commission can and does grant exemptions to specific requirements in our regulations as long as we assure adequate protection is achieved by other means. Moreover, we also have regulations which go beyond adequate protection and have been issued to enhance safety e.g. the Station Blackout Rule. Thus, if an "enhancement" passes the tests of the Backfit Rule, there is nothing to prohibit its imposition other than the guidance provided by the Safety Goals policy.

of uncertainty, recognizing that it is not quantifiable in a fashion similar to the other objectives. The current wording of the policy statement contains such a message implicitly; therefore, the Commission does not believe a change is necessary. The staff should, however, recognize this as a major element of uncertainty when referring to the safety goals in making regulatory decisions.

cc: Chairman Carr
Commissioner Roberts
Commissioner Rogers
Commissioner Curtiss
Commissioner Remick
OGC
GPA
IG
ACRS
ASLAP
ASLBP