ERDA-1535

Final Environmental Statement

LIQUID METAL FAST BREEDER REACTOR PROGRAM

December 1975

United States
Energy Research & Development
Administration

Volume 1
Of 3 Volumes

Summary and
Supplemental Material

MASTER

DISCLAIMER

SUMMARY SHEET

FINAL ENVIRONMENTAL STATEMENT

LIQUID METAL FAST BREEDER REACTOR PROGRAM

(ERDA-1535)

U.S. ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

1. This Final Environmental Statement (ERDA-1535) is issued in support of ERDA's program for the development of Liquid Metal Fast Breeder Reactor (LMFBR) technology. The Draft Environmental Statement was issued in March 1974, and the Proposed Final Statement (PFES) in January 1975, by the Atomic Energy Commission for public review. The PFES was issued in order to provide the Administrator of the Energy Research and Development Administration (ERDA) an opportunity to review the LMFBR statement and program before issuing a Final Statement to complete the NEPA review process. This Final Statement incorporates the PFES and supplemental information required as a result of the Administrator's review of it.

2. The objective of the LMFBR Program is to develop an environmentally acceptable and technically feasible option for meeting the Nation's electrical energy requirements.

3. Potential environmental and other effects of the outgrowth of the LMFBR Program including a postulated LMFBR-based electric power industry have been considered. Commercial utilization of the LMFBR when compared with currently available electricity production systems could extend low cost uranium reserves from decades to centuries, reduce the environmental impacts from waste heat discharges, air pollution, mining, milling, and enrichment of uranium, and provide substantial economic benefits in the reduction of fuel cycle costs. Utilization of the LMFBR would involve several recognized problems that are inherent in nuclear fuel cycles, including the safeguarding of nuclear materials and facilities against theft or sabotage, the management of radioactive wastes, the safety of the reactor and the protection of the public from the health effects of transuranic materials.

4. Alternative technology options include:

   a. Electrical generation using other energy sources including fossil and nuclear fuels, and hydroelectric, solar, wind, tidal, and geothermal energy.

   b. Improved energy conversion and storage devices including MHD, fuel cells, batteries, and gas turbines.

   c. Conservation of electrical energy.

   Alternatives to the reference LMFBR program plan that were considered were:

   a. Options that stretch out the program.

   b. Options that accelerate the program.

   c. Options that involve a change in program philosophy.

5. Written comments on the PFES were received from the Departments of: Agriculture, Commerce, Defense, Health, Education, and Welfare, Interior, State, and Transportation; the Arms Control and Disarmament Agency, Central Intelligence Agency, Environmental Protection Agency, Federal Energy Administration, Federal Power Commission, National Aeronautics and Space Administration, Nuclear Regulatory Commission, National Science Foundation; and State agencies, industrial, environmental and other public groups and individuals.

6. The Final Environmental Statement was forwarded to the Council on Environmental Quality on December 31, 1975, and an announcement as to its availability has been submitted to the Federal Register.

Additional information about the LMFBR Program or Final Environmental Statement can be obtained from Merrill J. Whitman, U.S. Energy Research and Development Administration, Washington, D. C. 20545, (301) 973-4366.

ADMINISTRATOR'S FINDINGS ON THE
LIQUID METAL FAST BREEDER REACTOR PROGRAM
FINAL ENVIRONMENTAL STATEMENT

1. On June 30, 1975, I issued my findings on the Proposed Final Environmental Statement (PFES) for the Liquid Metal Fast Breeder Reactor (LMFBR) Program which was released by the former Atomic Energy Commission on January 17, 1975. In summary, I found that the PFES amply demonstrated the need to continue research, development, and demonstration of the LMFBR concept, which could provide an essentially inexhaustible energy source to meet a significant share of our Nation's energy needs in the next century. However, I also found that significant problems had to be resolved satisfactorily before any decision could be made to place LMFBR's into widespread commercial use. Continuation of the program of research, development, and demonstration was necessary to resolve these problems, but would not prejudge any later decision concerning commercialization of this technology. Before issuing the Statement in final form, I called for an examination of alternative methods of conducting the program to be sure that--

(a) the research, development, and demonstration activities are properly directed to resolve the remaining technical, environmental, and economic issues in a definitive and timely way;

(b) these issues are resolved before a final decision concerning the acceptability of commercial deployment is made; and

(c) test and demonstration facilities that are needed in the LMFBR Program are conservatively designed to protect the health and safety of the public and to provide useful information for subsequent environmental, economic, and technical assessments.

Finally, I recognized that ERDA has a clear responsibility for making a determination, in accordance with the National Environmental Policy Act (NEPA), on whether commercial deployment of the LMFBR concept is warranted, even though no commercialization would be possible without favorable licensing action by the Nuclear Regulatory Commission and even though the Commission, as a result of the Energy Reorganization Act of 1974, is in no way bound by any future ERDA recommendation that the technology is ready for commercial use. I affirm all of these findings.

2. After review of the Final Environmental Statement (FES), which incorporates the PFES to the extent consistent with my earlier findings and provides the supplementary review of alternatives I called for, and upon the consequent conclusion of the NEPA process, I hereby make the following additional findings.

3. I find that the FES is not, and cannot be at this stage of LMFBR technology development, a dispositive assessment of the impacts of widespread commercial deployment of that technology. Nevertheless, I find that the FES does provide sufficient information on the foreseeable impacts of such deployment and on the programmatic alternatives available to resolve the major areas of uncertainty affecting such deployment, so that I now am in a position to determine the structure and pace of a

research, development, and demonstration program to provide a more dispositive assessment of those impacts and to resolve those areas of uncertainty in a timely manner.

4. The FES shows that the major areas of uncertainty lie in plant operation, fuel cycle performance, reactor safety, safeguards, health effects, waste management, and uranium resource availability. I find that the availability of sufficient information to resolve these areas of uncertainty is crucial before ERDA can render a meaningful decision on the commercialization of that technology, i.e., the environmental acceptability, technical feasibility and economic competitiveness of LMFBR technology for widespread commercial deployment.

5. ERDA has programs in place in each of these areas. The LMFBR Program has focused on plant operation through the development of experience in LMFBR demonstration plants, on fuel cycle performance through its base program of fuel cycle development, and on reactor safety which is an integral part of both the plant demonstration program and the base program. The other areas of uncertainty - safeguards, health effects, waste management and uranium resource availability - are not unique to the LMFBR, and are being addressed generically by other programs which have schedules not susceptible to significant acceleration. Measured against the schedules for these programs, the FES evaluates eight options for structuring the necessary research, development and demonstration program for LMFBR technology. These options are structured to

reflect changes in the timing and number of prototype reactor plants and various component test facilities, and the consequent changes necessary in the supporting base program, thus reflecting a wide range of program strategies. The program alternatives are compared on a cost-benefit basis including the evaluation of risks resulting from acceleration of the program. They are also compared on the basis of meeting the requirement for operation of a LMFBR demonstration or large prototype plant in a utility environment and for sufficient assurance of the technical feasibility, economic competitiveness and environmental acceptability of an LMFBR economy prior to any irreversible commitment to widespread commercial deployment.

6. Using the foregoing requirements, I rejected those options involving rapid acceleration of the program because of the lack of any demonstration or large plant experience and insufficient information in the areas of fuel cycle performance, reactor safety, safeguards, waste management, and health effects before a commitment would be made to commercialization. Those options involving major delays in the program were likewise deemed unacceptable because of the resulting loss of net economic benefits and of insurance against a potentially inadequate uranium resource and the inefficiencies in the conduct of the program. Finally, I rejected those program options which postulated omitting the Clinch River Breeder Reactor (CRBR) Plant because, in my judgment, the CRBR offers the most timely and cost-effective construction, licensing and operating experience essential to the successful completion of the LMFBR Program.

7. On balance, I find that the issue of plant operation in a utility environment is best addressed by the program plan entitled "reference plan". This plan contemplates construction and operation of the CRBR, a Prototype Large Breeder Reactor (PLBR), and a Commercial Breeder Reactor (CBR-1) on a schedule which calls for operation for three years of a Nuclear Regulatory Commission - licensed CRBR and completion of the design, procurement, component fabrication and testing phases for, and issuance by the Nuclear Regulatory Commission of a construction permit for, the PLBR prior to a commitment to construct the CBR-1. In my judgment, this schedule should provide sufficient experience in design, procurement, component fabrication and testing, licensing and plant construction and operation from CRBR and PLBR taken together to enable ERDA to predict with confidence the successful construction and operation of the CBR-1. This schedule will be periodically re-examined to assure that the experience derived from operation of the CRBR and the pre-operation of the PLBR is sufficient before ERDA commits itself to construction of the CBR-1. Moreover, a separate NEPA review of each of these plants will be undertaken on a site-specific basis to assure that they are environmentally acceptable and are conservatively designed to protect the health and safety of the public and to provide useful information for subsequent environmental, economic, and technical assessments.

8. The base program consists of necessary supporting efforts which proceed relatively independently of the plant demonstration program. These

efforts focus on the development of advanced fuels and of a fuel reprocessing system. Key to these efforts is the design, construction and operation of an LMFBR fuel reprocessing hot pilot plant. The FES indicates that completion of the design work for this plant and its equipment would provide an adequate basis upon which to predict with confidence whether a safe, reliable, and economical LMFBR fuel cycle will be developed.

9. The FES also addresses major uncertainties in the areas of reactor safety, safeguards, waste management, health effects, and uranium resource availability. In reviewing the programs in each of these areas, I find that the controlling item currently appears to be the construction of and testing in a large scale safety test facility. While the results of these tests are not required to assure the safety of early demonstration plants, they are required to provide realistic design conservatism for commercial plants. Alternative methods for conducting these tests are being evaluated, and I will separately make a final decision on the conduct of these tests at a later date.

10. On the basis of the material set forth in the FES, I find that if the reference plan and its supporting programmatic efforts are vigorously pursued, sufficient information would be available as early as 1986 to resolve the major uncertainties affecting widespread LMFBR technology deployment and therefore to permit an ERDA decision on commercialization of that technology. It should be emphasized that availability of the

necessary decisional data by 1986 requires the successful and timely completion of a large number of interrelated and parallel efforts. Delay in any of the aforementioned controlling elements will result in a delay of the decision date. It should be emphasized also that following an ERDA decision on commercialization the utility industry and the public would have to determine the extent, if any, LMFBR technology would be commercially deployed.

11. To be meaningful, ERDA's decision on commercialization must be made before any commitment to widespread deployment becomes irreversible. In this connection, I do not find that implementation of the LMFBR Program, as structured above, would constitute an irreversible commitment to widespread commercial use in 1986. At that time CRBR would have been in operation three years, construction would have been largely completed on the PLBR, and the CBR would still be in the design stage. The level of program involvement of the industrial sector would be minor compared to the investment required to place LMFBR technology in widespread use. Moreover, if ERDA were to determine that the problems involved in widespread deployment could not be resolved satisfactorily, the Nuclear Regulatory Commission would almost surely refuse to license LMFBR plants.

12. Nor do I find that continuation of the LMFBR Program, as structured above, would inevitably short-change the development of other technology programs for the long term production and conservation of energy. Indeed,

these technological alternatives are receiving substantially increased new appropriations and are proceeding as rapidly as possible consistent with prudent management.

13. In conclusion, it must be emphasized that at this stage of LMFBR technology development we do not have all the answers necessary to determine the environmental acceptability, technical feasibility and economic competitiveness of LMFBR technology for widespread commercial deployment. It is to find these answers that ERDA is continuing the research, development, and demonstration program. As the LMFBR Program and its supporting programs continue to evolve and new information is generated, ERDA may decide to reorient the structure or pace of the LMFBR Program or even terminate it altogether. That is why the findings I make today must be periodically re-evaluated in the light of new information. In any event, at least one additional programmatic environmental statement will be prepared and considered prior to any future ERDA decision on the commercialization of LMFBR technology. The current planning schedule calls for the preparation and consideration of such a programmatic statement in 1986.

Robert C. Seamans, Jr.

Robert C. Seamans, Jr.
Administrator

December 31, 1975

ERDA-1535

Final Environmental Statement

LIQUID METAL FAST BREEDER REACTOR PROGRAM

December 1975

United States
Energy Research & Development
Administration

Volume 1
(of 3 Volumes)

Responsible Official:

James L. Liverman
Assistant Administrator For
Environment & Safety

ALPHABETICAL LIST OF ABBREVIATIONS, SYMBOLS AND ACRONYMS USED IN THE STATEMENT

A	ampere
AC	alternating current
ACRS	Advisory Committee on Reactor Safeguards
AD/R	Assistant Director for Reactor Safety
ADU	ammonium diuranate
AEC	Atomic Energy Commission
AEC-RL	AEC - Richland Operation
AI	Atomics International
AMAD	activity median aerodynamic diameter
ANC	Aerojet Nuclear Corporation
ANL	Argonne National Laboratory
ANPO	Aircraft Nuclear Propulsion Office
ARHCO	Atlantic Richfield Hanford Company
AWSF	Alpha Waste Storage Facility
Ag	silver
Am	americuim
As	arsenic
Ar	argon
Avg.	average
atm.	atmosphere
BEIR	Biological Effects of Ionizing Radiation (Committee)
Btu	British thermal unit
BRC	Breeder Reactor Corporation
BWR	boiling water reactor
B&W	Babcock and Wilcox
Bi	bismuth
Br	bromine
BNL	Brookhaven National Laboratory
b	barn
CBR	Commercial Breeder Reactor
CCD	counter-current digestion (ore leach process)
CE	Combustion Engineering
CEA	Commissareat à l' Energie Atomique
CEQ	Council on Environmental Quality
CIA	Central Intelligence Agency
CF	Confinement factor
CFR	Code of Federal Regulations
CRBR	Clinch River Breeder Reactor
CRBRP	Clinch River Breeder Reactor Plant
CTR	Controlled Thermonuclear Reactor
CWP	Coal worker's pneumoconiosis (black lung)
Cf	californium
cfs	cubic feet per second
°C	degrees Centigrade
Ci	curie
C	carbon (carbide)
Ca	calcium
Ce	cerium
Cm	curium
cm	centimeter
cm_2	square centimeter
cm_3	cubic centimeter
Co	cobalt
Cs	cesium
CO	carbon monoxide
CO_2	carbon dioxide
DC	direct current
DF	decontamination factor
DOD	Department of Defense
$/sec	dollars per second (reactivity insertion rate)
DOP	dioctyl phosphate
DOT	Department of Transportation
DTPA	diethylenetriaminepentaacetic acid
diam.	diameter
dis	disintegration
EBR-I	Experimental Breeder Reactor - I
EBR-II	Experimental Breeder Reactor - II
EEI	Edison Electric Institute
EHV	Extra High Voltage
EIAP	Environmental Impact Assessment Project
EIS	Environmental Impact Statement
ENDF/B	Evaluated Nuclear Data File - B
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ERDA	Energy Research and Development Administration
ETR	Engineering Test Reactor
Eu	europium
°F	degrees Fahrenheit
FBI	Federal Bureau of Investigation
FEA	Federal Energy Administration
FEFP	Fuel Element Failure Propagation
FFM	Fuel Failure Mock-Up
FHA	Federal Housing Adminstration
FFTF	Fast Flux Test Facility
FPC	Federal Power Commission
FSAR	Final Safety Analysis Report
ft	foot (feet)
ft^2	square feet
ft^3	cubic feet
Fe	iron

GAC	Gulf Atomic Corporation
GAO	General Accounting Office
GCFR	Gas Cooled Fast Reactor
GE	General Electric Company
GETR	General Electric Test Reactor
GI	gastro-intestinal
GNP	gross national product
GW	gigawatt
GWe	gigawatt electric
GWt	gigawatt thermal
g	gram
gal	gallon
gpd	gallon per day
gpm	gallon per minute
H	hydrogen
H-3	tritium
HCDA	hypothetical core disruptive accident
HEDL	Hanford Engineering Development Laboratory
HEPA	high efficiency particulate air (filter)
HEW	Health, Education and Welfare (Dept. of)
HF	hydrogen fluoride
HNL	Holifield National Laboratory
HPFL	High Performance Fuels Laboratory
HPOF	high pressure oil filled (cable)
HPP	Hot Processing Plant
HTGR	High Temperature Gas Reactor
HVDC	high voltage direct current
hr.	hour
I	iodine
IAEA	International Atomic Energy Agency
ICC	Interstate Commerce Commission
ICRP	International Commission on Radiological Protection
ID	inside diameter
IRAP	Interagency Radiological Assistance Program
in	inch (es)
K	potassium
°K	degrees Kelvin
Kr	krypton
Kv	kilovolt
k eff	effective multiplication constant
kCi	kilocurie (1000 curies)
kg	kilogram
km	kilometer
kV	kilovolt
kW	kilowatt
kWe	kilowatt electric
kWhr	kilowatt-hour
kWt	kilowatt thermal
LASL	Los Alamos Scientific Laboratory
LAMPRE	Los Alamos Molten Plutonium Reactor Experiment
LE	limit of error
LET	linear energy transfer
LLL	Lawrence Livermore Laboratory
LMFBR	Liquid Metal Fast Breeder Reactor
LNG	liquid natural gas
LOA	Line of Assurance
LOCA	loss of coolant accident
LSA	low specific activity
LWBR	Light Water Breeder Reactor
LWR	Light Water Reactor
l	liter
lb	pound
Max	maximum
MBtu	million Btu
MeV	million electron volts
MHD	magnetohydrodynamics
MIT	Massachusetts Institute of Technology
MPC	maximum permissible concentration
MSBE	Molten Salt Breeder Experiment
MSBR	Molten Salt Breeder Reactor
MT	metric ton (tonne)
MTU	metric ton of uranium (metal)
MUF	material unaccounted for
MW	megawatt
MWd	megawatt-day
MWe	megawatt electric
MW-sec	megawatt-second
MWt	megawatt thermal
m	meter
m^2	square meter
m^3	cubic meter
mb	millibarn (10^{-3} barn)
mCi	millicurie (10^{-3} curie)
μb	microbarn (10^{-6} barn)
μCi	microcurie (10^{-6} curie)
MCi	megacurie (10^6 curies)
μm	micrometer
mg	milligram
min	minute
ml	milliliter
mph	miles per hour
Mn	manganese
mrem	millirem
msec	millisecond (10^{-3} second)
N_2	Nitrogen
N/A	not applicable

NASA National Aeronautics and Space Administration
NAS-NRC National Academy of Sciences - National Research Council
NCBR Near Commercial Breeder Reactor (also designated Prototype Large Breeder Reactor)
NEPA National Environmental Policy Act
NFS Nuclear Fuel Services
NGSF Noble Gas Storage Facility
NRC Nuclear Regulatory Commission
NRDC Natural Resources Defense Council, Inc.
NRTS National Reactor Test Station
NSF National Science Foundation
NSSS nuclear steam supply system
NURE National Uranium Resource Evaluation
Nb niobium
Np neptunium
NO_2 nitrogen dioxide
NO_x oxides of nitrogen
nCi nanocurie (10^{-9} curie)

OD outside diameter
O+M Operation and Maintenance
OMB Office of Management and Budget
OP oxygen pressure process (ore leach process)
OPERA Out-of-Pile Expulsion and Re-entry Apparatus
ORNL Oak Ridge National Laboratory

PAHR Post Accident Heat Removal
PBF Power Burst Facility
PCRV prestressed concrete reactor vessel
PCTF Plant Component Test Facility
PFES Proposed Final Environmental Statement
PLBR Prototype Large Breeder Reactor
PMC Project Management Corporation
PNL Pacific Northwest Laboratory
PSAR Preliminary Safety Analysis Report
P&W Pratt and Whitney
PWR Pressurized Water Reactor
pCi picocurie (10^{-12} curie)
ppb parts per billion
ppm parts per million
psi pounds per square inch
psia pounds per square inch, absolute
psig pounds per square inch, gauge
Pb lead
Pm promethium
Pu plutonium
PuO_2 plutonium dioxide
Quad 10^{15} Btu

°R degrees Rankine
R Roentgen
R&D research and development
RL Richland Operations Office
RRD Reactor Research and Development Division
RSSF Retrievable Surface Storage Facility
rpm revolutions per minute
Rb rubidium
Ru ruthenium

SAR Safety Analysis Report
SAREF Safety Research Experiment Facility
SCTI Sodium Components Test Installation
SEFOR South-East Fast Oxide Reactor
SIPI Scientist's Institute for Public Information
SLSF Sodium Loop Safety Facility
SNG synthetic natural gas
SNM special nuclear material
SPTF Sodium Pump Test Facility
SRE Sodium Reactor Experiment
SS Stainless steel
STF Safety Test Facility
STP standard temperature and pressure
SWU separative work unit
scfm standard cubic feet per minute
sec second
sq. ft. square feet
Sb antimony
Sr strontium
SO_2 sulfur dioxide
SO_x oxides of sulfur

TEG thermoelectric generator
TFE thermionic fuel element
TGLM task group lung model (ICRP)
TREAT Transient Reactor Test (Facility)
TVA Tennessee Valley Authority
TVR Tennessee Valley Region
Te tellurium
Tonne metric ton

U uranium
UHV ultra high voltage
UMRB Upper Mississippi River Basin
UO_2 uranium dioxide

U_3O_8	black oxide of uranium
UF_6	uranium hexafluoride
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
USAEC	United States Atomic Energy Commission
USGS	United States Geological Survey
W	watt
WARD	Westinghouse Advanced Reactors Division
We	watt electric
WEP	water extended polyester
WLM	working-level month
wt.%	weight percent
w/o	without
Xe	xenon
Y	yttrium
yr	year
Zr	zirconium

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II. PROPOSED FINAL ENVIRONMENTAL STATEMENT FOR THE LIQUID METAL FAST BREEDER REACTOR PROGRAM, DECEMBER 1974, WASH-1535

III. SUPPLEMENTAL MATERIAL

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PREFACE

The ability of nuclear energy to help meet the Nation's electric power requirements depends upon the continued availability at reasonable cost of the uranium-235 isotope for the nuclear fuel. However, the relative scarcity of this isotope in natural uranium (0.7%) limits total energy recovery from current reactor systems to 2% or less of that prospectively available from natural uranium. Thus, the long-term advantages of generating electricity from nuclear fission may be severely constrained unless large additional quantities of natural uranium are found in nature, or unless substantial improvements can be achieved in the efficiency of uranium use. The breeder reactor has been looked upon as offering the prospect for highly efficient uranium utilization and a long-term solution to the continued generation of low cost electrical power.

It is known that a Liquid Metal Fast Breeder Reactor (LMFBR) can produce enough plutonium-239 to refuel itself completely. After 10 to 15 years of operation, each breeder plant would accumulate sufficient surplus plutonium to provide start-up fuel for another reactor of comparable size. It is further estimated that initiation of a breeder reactor economy could lead to the utilization of more than 60% of the total energy from uranium.

Accordingly, a research and development program was initiated in the 1950's and was substantially expanded in the late 1960's to develop an LMFBR option which would be capable of meeting a substantial portion of this Nation's electric power requirements. The extent to which this option would be exercised is recognized to be dependent upon its successful development and subsequent endorsement by the utility industry and the public. The LMFBR Program had already proceeded through the first research and development phase -- demonstration of the feasibility of breeder reactors and confirmation of the basic technical aspects -- and was already well into the second phase -- development of engineering understanding -- when the National Environmental Policy Act (NEPA) went into effect on January 1, 1970. NEPA has served to institutionalize important aspects of the Governmental decision-making process by assuring that environmental as well as other implications are considered at every stage of that process and by affording a meaningful opportunity for public participation. The primary mechanism through which the environmental factors are considered is the preparation of an environmental impact statement.

The Atomic Energy Commission (AEC) had already issued two environmental impact statements in the fast breeder reactor area -- one in connection with its LMFBR test facility, the Fast Flux Test Facility,[1] and one dealing with a conceptual LMFBR demonstration plant[2] -- when on June 12, 1973, the U. S. Court of Appeals for the District of Columbia Circuit ruled that NEPA requires present preparation of an environmental statement on the impacts of LMFBR technology development.[3]

In accordance with Guidelines of the Council on Environmental Quality (CEQ) and its own regulations (10 CFR Part 11), the AEC issued a Draft Statement on March 14, 1974 for review and comment by Federal, state, and local agencies; interested environmental, industrial and other organizations; and the general public. Suggestions from these groups as to the scope and content of the Statement had already been solicited by Federal Register Notice of October 4, 1973. After consideration of extensive comments submitted in writing and at a Public Hearing held on April 25-26, 1974, the Statement was prepared in final form. However, the AEC released it in January 1975 as a Proposed Final Environmental Statement (PFES), in view of the forthcoming establishment of the Energy Research and Development Administration (ERDA) on January 19, 1975, and the realization that future decisions on such a significant long-term developmental program were properly for ERDA to make and that ERDA would have a different perspective than the AEC in view of ERDA's statutory mandates to conduct research, development and demonstration programs in both nuclear and non-nuclear energy sources. Issuance in this form permitted ERDA, in accordance with the AEC's recommendation, and with the concurrence of CEQ, to provide another round of written comments and another Public Hearing on May 27-28, 1975, on the Statement and the LMFBR Program.

The Public Hearing was conducted by an Internal Review Board which had been selected by the Administrator of ERDA from senior ERDA officials* not previously involved in the Statement's preparation. They were requested to review the PFES and the comments received on it and to report to the Administrator on whether the issues relevant to a decision on the LMFBR Program were adequately treated in the PFES, whether the options in the PFES had been adequately evaluated, and whether all relevant options had been considered.

The Internal Review Board submitted its Report to the Administrator on June 20, 1975. That Report concluded that:

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*Mr. Robert W. Fri, Deputy Administrator, Dr. John M. Teem, Assistant Administrator for Solar, Geothermal and Advanced Energy Systems, Dr. James S. Kane, Deputy Assistant Administrator for Conservation, Dr. S. William Gouse, Deputy Assistant Administrator for Fossil Energy.

- the PFES is a sufficient factual record for determining whether the LMFBR Program should be continued and there are no clearly available and prudent alternatives to a continuation of the Program at the present time;

- the PFES fails to provide a sufficient basis for a choice among possible Program courses which could structure the Program in an optimum fashion;

- the PFES is not sufficiently complete or accurate with respect to several matters bearing upon the environmental acceptability of deployment of the technology. On the other hand, the record strongly suggests that the unresolved environmental problems and the uncertainties concerning technological alternatives are amenable to solution, wholly or partially, in the course of the ongoing research and development program;

- ERDA should develop a final environmental impact statement incorporating the PFES by reference and including the following specific additional information in order to ensure that the record before the Administrator is adequate for him to choose the optimum course for the LMFBR Program:

  - A discussion of the sequence of steps, timing, problem definition and methodology of the various ongoing studies and programs which are relevant to the environmental and economic acceptability of an LMFBR industry. These studies include the LMFBR safety program and related inquiries concerning safeguards, waste management and uranium resource availability.

  - An identification of the optimal points in the LMFBR Program plan at which the major issues related to reactor safety, safeguards, waste management and uranium resource availability can be expected to be resolved.

  - An indication of the optional courses of action available to the Administrator in structuring the LMFBR Program, so that a present decision can be made on that Program, while at the same time reserving for later judgment the question of whether implementation of the technology is acceptable.

  - A description of the minimization concepts listed in the PFES and an assessment of the extent to which each of these can reduce the safeguards risk.

- An indication of the points at which reliable information on alternative technologies for the production and conservation of energy will become available for further consideration.

Upon review of the PFES, the written comments and public hearing record, the Internal Review Board Report (which the Administrator adopted) and the written views of several knowledgeable scientific and technical individuals outside ERDA* and after consideration of the PFES in relation to ERDA's comprehensive national energy plan,[4] the Administrator issued Findings on June 30, 1975. The Administrator found, in pertinent part, as follows:

"7. The PFES amply demonstrates the need to continue research, development and demonstration of the LMFBR concept. There is no presently available or prudent alternative to this course of action. This technology holds the promise of an essentially inexhaustible source of energy to satisfy a significant share of this Nation's energy needs in the next century. While LMFBR technology is not the only technology which may be able to satisfy this objective, significant uncertainties concerning timely availability of the other major candidates, which are solar electric and fusion energy, make it risky and imprudent to discard the LMFBR Program on the basis of what we presently know. It is simply too soon to confirm with sufficient reliability that these alternate technologies will be available on time and in adequate quantity. It is speculative at this time that these options would be environmentally preferable to the LMFBR technology. Moreover, while I do not adopt any particular growth projection, including those postulated in the PFES, I cannot now discount the possibility that contributions from all three technologies will be desirable or needed to meet future energy demands. The possible needs are such, and the promise of energy from inexhaustible sources so great, that all three technologies must be pursued on a priority basis.

"8. In the light of these considerations, only a demonstration that the LMFBR can <u>not</u> be developed as a safe, environmentally sound and economically competitive energy source would justify a decision to discontinue the program. The record before us does not so indicate. I adopt the conclusion of the PFES and the Review Board that the significant problems identified in the LMFBR concept may be solved by a continuation of the Program.

*Mr. Walter H. Zinn, a consultant and former Combustion Engineering, Inc. executive, Dr. Alvin M. Weinberg of the Institute for Energy Analysis and former Director of the Oak Ridge National Laboratory, Mr. Donald B. Rice, President of the Rand Corp., and Dr. Cyril L. Comar, Director of the Environmental Assessment Department, Electric Power Research Institute.

"9. At the same time, these significant problems, as identified by the Board, including in particular those related to reactor safety, safeguards, health effects, and waste management, remain unresolved at this time. They must be resolved satisfactorily before any decision may be made to place LMFBR's into widespread commercial use. I concur with the Board that research, development and demonstration are needed to resolve these matters and that the PFES as it stands is not and cannot be a conclusive or satisfactory assessment of the environmental impact of a fully commercialized breeder reactor industry. Continuation of the research, development and demonstration program does not prejudge any decision concerning the commercialization of this technology. I concur with the Board that while these two questions are related, they can be separated from each other. I find that continuation of the LMFBR Program at this time would not lead inexorably or irresistably to a full 'breeder economy,' if further work were to demonstrate that the problems of the breeder cannot be resolved. Specifically, I do not find that completion of the Clinch River Breeder Reactor (CRBR) project,* an integral part of the Program, is tantamount to widespread commercialization. As a practical matter, NRC would almost surely refuse to license breeder reactors if there were an ERDA finding that major problems were unresolvable. At the same time, as indicated above, NRC (unlike the former AEC) would be in no way bound by an ERDA environmental impact statement or an ERDA recommendation that the technology was ready for commercial use. Nor do I find that continuation of the program at this time would inevitably short-change the other technologies we must develop. Indeed, these other programs are receiving substantially increased new appropriations and are proceeding as rapidly as possible consistent with prudent management and efficient use of public monies.

"10. It will be necessary over the next few months to carefully reexamine the current developmental program to be sure that it is most efficiently structured to solve the problems that need solution. A major weakness of the PFES is that aside from termination no alternatives are presented to continuing the program precisely as set forth in the PFES. As Administrator, I need to consider alternative methods of conducting the program to be sure that -

(a) the research, development and demonstration activities are properly directed to resolve the remaining technical, environmental, and economic issues in a definitive and timely way;

*It is noted that the CRBR is subject to a separate site-specific environmental impact statement, which will be issued in connection with the application for licensing of the demonstration plant.

(b) these issues are resolved before a final decision concerning the acceptability of commercial deployment is made; and

(c) test and demonstration facilities that are needed in the LMFBR Program are conservatively designed to protect the health and safety of the public and to provide useful information for subsequent environmental, economic, and technical assessments.

"11. The PFES will be supplemented or amended, as appropriate, to reflect these conclusions and provide the information called for above. The resulting document, which will constitute ERDA's Final Environmental Statement and complete the NEPA process on this action, will be issued within approximately three months. Meantime, the Program will be carried forward at the rate and level of authorization reflected in Congressional action on the budgetary proposals ERDA has recently submitted. Because the CRBR Project has been substantially delayed, this decision entails no environmentally irreversible action during this period and for substantially more than thirty days after the Final Statement is issued.

"12. ERDA will maintain continuing scrutiny on the LMFBR research, development and demonstration program as it develops. ERDA clearly has the responsibility to make a determination whether commercial deployment of the LMFBR concept is warranted, although it is also true that no commercialization is possible without favorable licensing action by NRC. Accordingly, as the program develops and significant new information pertinent to the commercial deployment issue is generated, ERDA will update the existing Environmental Statement or prepare a Supplement to it, or even a new Statement, as may be appropriate and consistent with the National Environmental Policy Act. On the basis of this updated record, together with the periodic revision of the LMFBR Program, and the annual updating of the Comprehensive Energy Research and Development Plan, ERDA will subsequently evaluate the environmental acceptability and economic feasibility of widespread commercial use of LMFBR's. To be meaningful, this consideration will take place before any commitment to widespread commercial use becomes irreversible. At the same time, ERDA will pursue, as vigorously as result-oriented management will permit, programs for long-term energy technologies that can be evaluated by this agency, the Congress, and the marketplace as alternatives or supplements to breeder reactors."

In short the Administrator found that the PFES was adequate to determine that the LMFBR Program should continue, that additional information was necessary in an FES to presently determine the structure and pace of that Program, and that at least one additional NEPA review would be undertaken before ERDA could make a decision on the acceptability of widespread commercial deployment of LMFBR technology.

The Final Environmental Statement (FES) has been prepared in accordance with the instructions conveyed in the Administrator's Findings.

- The Summary contains a brief account of the additional information (Sections I and III) found necessary by the Administrator to complete the present NEPA review.

- Section I focuses on the Administrator's requirement for an analysis of the range of options available for structuring the LMFBR Program and the compatibility of those options with the timely resolution of the major environmental issues involved in widespread commercial LMFBR deployment.

- Section II incorporates the PFES by reference to the extent consistent with the Administrator's Findings of June 30, 1975.

- Section III contains a detailed discussion of the major environmental issues, a review of uranium resource availability, an analysis of the key decision points in the development of major alternatives to the LMFBR, a compilation of substantive revisions to the text of the PFES, and supplemental material in areas requiring updating of the PFES (e.g., cost-benefit analyses).

- Section IV includes the Administrator's Findings as well as copies of the reports pertinent to the Administrator's evaluation of the PFES.

- Section V contains copies of the 88 letters received in response to requests for comments on the PFES and the ERDA responses to each letter.

In order to be responsive to the Court's decision and to reflect the broad and balanced approach to energy research and development which is ERDA's unique mission, the FES taken as a whole attempts to describe the reasonably foreseeable environmental, social, technological and economic costs and benefits of a prospective mature LMFBR economy (to determine if it is desirable to continue to pursue a program of research, development and demonstration of the LMFBR concept), the potentially available alternatives to such a mature LMFBR economy and their reasonably foreseeable costs and benefits, and the alternative ways of structuring a research, development and demonstration program to resolve the issues involved in widespread commercial LMFBR deployment.

This is the first environmental impact statement which attempts to address in a comprehensive manner the potential future impacts of a prospective, large-scale source of electric energy still under development. The detailed visualization of an industry involving plants and facilities that have not yet been designed is extremely difficult. Major reliance has been placed, therefore, on analogies to the existing nuclear fission industry, and an evaluation has been made of the reasonably foreseeable environmental effects that would result from construction and operation of model plants in the LMFBR fuel cycle -- the breeder reactor power plant, the fuel fabrication plant, the fuel reprocessing plant, and the waste storage and disposal facilities -- plus the transportation of fuel and radioactive material between these plants and facilities. Obviously, it is not possible at this stage in the research and development program to determine in a precise manner the environmental effects of LMFBR fuel cycle operations. In these circumstances the FES contains values that are purposely conservative, but it is one of the main purposes of the extensive research and development program currently underway to develop information necessary to evaluate the environmental effects more precisely. Furthermore, many of the operational effects are dependent on the sites and on the specific facility designs which are not yet available at this stage of the research and development program. Indeed, it must be emphasized that an environmental impact assessment based on a specific plant site, on the specific design of the plant, and on the plant's interactions with other parts of the fuel cycle will be performed for each LMFBR plant or fuel recycle facility to be built in the future. Moreover, ERDA will prepare one or more additional program statements prior to making a decision with respect to the acceptability of widespread commercial deployment of LMFBR technology. It is anticipated that the information will be available for ERDA to be in a position to make such a decision as early as 1986. No irreversible course of action towards widespread commercial deployment will be taken until such a program statement has been prepared and considered.

REFERENCES FOR PREFACE

1. U.S. Atomic Energy Commission, "Fast Flux Test Facility -- Environmental Statement," WASH-1510, May 1972.

2. U.S. Atomic Energy Commission, "Liquid Metal Fast Breeder Reactor Demonstration Plant -- Environmental Statement," WASH-1509, April 1972.

3. Scientist's Institute for Public Information, Inc. v. AEC, 481 F. 2d 1079 (D.C. Cir. 1973).

4. U.S. Energy Research and Development Administration, "A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future," ERDA-48, June 1975.

SUMMARY

SUMMARY

1. INTRODUCTION

This section summarizes the following additional material included in the Final Environmental Statement in response to the Administrator's direction as set forth in his Findings on the Proposed Final Environmental Statement (see Section IV A):

- An analysis of the range of options available to the Administrator for structuring the LMFBR Program (Section I.3)
- An analysis of the major environmental issues involved in widespread LMFBR deployment (Section III) and the compatibility of the milestones for resolution of those issues with LMFBR Program milestones (Section I.4)
- A review of uranium resource availability (Section III E)
- A summary of the key decision points in the development of the major alternatives to the LMFBR, i.e., solar electric and fusion technology (Section III H)

2. ADMINISTRATOR'S DECISION POINTS ON LMFBR TECHNOLOGY

In accordance with the Administrator's direction, supplemental material has been provided on each of the subjects listed above. The decision points at which the Administrator can make a determination on the acceptability of the LMFBR technology for widespread commercial deployment have also been identified. These program decision points rest in turn on decision dates for three key program elements -- plant experience, base program and environmental issues -- for each of the alternative program plans analyzed. In order for the Administrator to make his determination, all three program elements must receive sufficient attention to permit confident prediction that the technology will be available when required.

In the case of plant experience it is believed that three years of operation after criticality of either the Clinch River Breeder Reactor Plant (CRBRP) or a larger LMFBR is necessary to develop the necessary confidence in the safety, reliability and maintainability of a breeder reactor system. The pacing item for the base research and development program in each plan is the demonstration of the fuel recycle technology (see Section I.3.4). The pacing items for the four environmental issues identified by the Administrator as requiring further resolution vary with the issue. The program in effect for each of the four issues is structured to supply sufficient information for the Administrator to be able to make his determination on the acceptability of the LMFBR technology for widespread deployment by 1986.

3. ALTERNATIVE LMFBR PROGRAM PLANS

The Administrator requested that alternatives to the present LMFBR Program be presented for his consideration in order to assure that the current development program is structured so as to resolve the issues relevant to a decision on the widespread commercial deployment of LMFBR technology. In response to this request seven alternatives to the current (reference) plan were examined. Although the major program effects are produced by changes in the timing and number of demonstration and large prototype reactor plants, as well as specific key facilities, the alternative plans represent significant changes in strategy.

Review of the base research and development program has revealed that the controlling element in the program is the development of a technically and economically adequate fuel reprocessing system. By 1986 all the design work for a LMFBR fuel reprocessing hot pilot plant and its equipment should be finished and construction should be well along. In addition, industry should be making contributions, with ERDA support, to a conceptual commercial plant study and to large scale component development and testing. These combined activities will provide data from which early projections of LMFBR fuel cycle economics and overall breeder power plant potential for commercialization can be assessed.

It has been concluded that an adequate basis will exist to predict the successful completion of a safe, reliable, and economical fuel cycle by 1986. At that time equipment design, development, and cold engineering operation will have been completed, the hot pilot plant will be in the final stages of construction, and reference chemical processing methods will have been verified. Operation of the hot pilot plant will provide valuable statistical information to permit engineering tradeoffs leading to economies in the process establishment of the large scale material balances, and will serve as an experience base for the construction and operation of full scale reprocessing plants. It will serve as a key facility for evaluation and for demonstration of improvements in fuel reprocessing technology. Although information developed from operation of the hot pilot plant will be important for design of the optimum fuel recycle plant and its economics, it is not considered necessary for this information to be developed prior to the decision on acceptability of LMFBR technology for widespread commercial deployment.

Another key element of the base research and development program is the development of advanced LMFBR fuels. The fuel development program objective is to provide a range of fuel options, so that the reactor designer can make a selection in 1986.

The reference program plan is founded upon a strong R&D base program with prototype testing and fuel cycle development as key elements. It includes a demonstration plant, the Clinch River Breeder Reactor Plant (CRBRP), and a Prototype Large Breeder (PLBR) in order to permit gradual extrapolation in size from the Fast Flux Test Facility (FFTF) to the full size LMFBR in accordance with good engineering practice. The program is designed to permit construction of the first Commercial Breeder Reactor (CBR-1) in time for criticality in 1993. The base research and development program is focused to resolve the key program element issues by 1986, before construction of CBR-1 is initiated.

The alternative program plans to the reference plan which were considered are:

- Plan 1 - The reference case without the Clinch River Breeder Reactor Plant (CRBRP).
- Plan 2 - The reference case with the CRBRP but with a change in strategy away from prototype testing.
- Plan 3 - A case resulting in moderate delay of the introduction of CBR-1.
- Plan 4 - A case resulting in moderate acceleration of the introduction of the CBR-1.
- Plan 5 - A highly accelerated case which includes the CRBRP but eliminates prototype large plants. The base technology program is reduced.
- Plan 6 - A highly accelerated case which eliminates the CRBRP as well as the prototype large plants, accelerates the program, and relies heavily on foreign experience.
- Plan 7 - A sequential case which results in extensive delay in the introduction of the CBR-1.

For each case the overall benefits,* costs and risks were calculated and compared to those of the reference program.

The plan without the CRBRP (Plan 1) involves a slippage in schedule of two years in the PLBR-1 and CBR-1 projects. The disadvantages involved in this approach relate directly to the loss of experience which would have been gained from construction, licensing, and operation of the CRBRP. The two year delay occurs because of a) the demobilization of the engineering teams (both reactor design and component vendors); b) the refocusing of the base technology and safety programs to obtain the necessary supporting data to permit the large extrapolation to full-size LMFBRs; c) delays in obtaining statistical fuel performance, breeding ratio and core performance data; d) greater difficulties and delays in achieving resolution of licensing problems without going through the experience of licensing the CRBRP; and e) increased construction time. The two year delay in reaching CBR-1 criticality (from 1993 to 1995) results in a $6 billion discounted loss in benefits derived from the LMFBR Program. The cost of the program is $1.7 billion less than the reference case. The increased risk resulting from this plan would probably require greater government support for PLBR-1 than called for in the reference plan.

A change in the program from the reference plan to Plan 2 represents a significant change in philosophy and strategy for conducting the program. In this case the Plant Component Test Facility (PCTF) is not constructed and the LMFBR Program is shifted away from the program philosophy of designing, developing and testing of large scale components in non-nuclear facilities prior to manufacture and insertion in a reactor plant. Plan 2 therefore represents a higher risk case in that design errors or performance defects must be corrected after installation in the plant and could significantly delay useful operation of the plant. In addition, there is a high risk that, because of unforeseen problems in PLBR-1, construction of CBR-1 would be delayed beyond the date shown in the Plan 2 schedule. Moreover, the base program is no longer expected to provide test information on full scale components. These higher risks could of course be offset if industry were to decide to build a test facility and test large scale components. The deletion of PCTF from the program resulted in a decrease of $290 million in direct program costs but resulted in increased risks to the program estimated to be in the range of $500-$1000 million. The benefits to the Nation are identical to the reference case since no perturbation in CBR-1 schedule is assumed but successful completion of the program in the same time period does not have as high a degree of assurance as the reference plan.

*Benefit is defined as the power cost savings to the Nation resulting from the generation of electricity by the LMFBR.

Two of the program plans evaluated the effects of delaying the reference plan. Plan 3 considered the effect of a moderate delay in the LMFBR Program resulting in a 3-year delay in CBR-1 criticality. This strategy decreased the risks in the program by increasing the amount of information transferred from CRBRP to PLBR-1 and similarly from PLBR-1 to CBR-1. The result of this program strategy was to reduce the direct program costs by $720 million, mainly because the LMFBR target costs (economic parity with LWR costs)* are greater. However, the delay of three years in CBR-1 introduction would decrease the benefits derived from the LMFBR by as much as $9 billion.

Plan 7 reviewed the effects of a more extensive delay in the program. This plan adopted a sequential strategy in which initiation of each successive project is delayed until the preceding project has been in operation a year. Although the increase in LWR economic target costs as a consequence of this delay resulted in a $2.85 billion reduction in direct program costs, the delay resulted in a 19 year lag in criticality for CBR-1 when compared to the reference case, practically eliminating LMFBR benefits through the year 2020. This plan was proposed in an effort to maximize data transfer from one plant to the next and thereby reduce risks. However, the constant mobilization and demobilization of reactor design, engineering and construction teams with the attendant losses of skilled experienced personnel vitiates much of this apparent gain.

The alternative program review also studied three options in which the program was accelerated to different degrees. Plan 4 considered the effect of a moderate acceleration in the reference program, advancing the introduction of CBR-1 by three years--from 1993 to 1990. The PCTF is eliminated and a second prototype large breeder, PLBR-2, is added to gain additional plant and component experience necessary to assure successful early introduction of CBR-1. The program cost increased $640 million, but the benefits increased as much as $9 billion because of early introduction of the LMFBR. The risks of accelerating the program in this manner (e.g., increased chance of delay in licensing, and less reliable systems and components) are considered to reduce these benefits to a substantial degree (up to $600 million in added component failure risk alone).

Plans 5 and 6 represented rapid accelerations in the program leading to introduction of CBR-1 five years earlier (1988 instead of 1993) than the reference case date.

*See Section I.3 for discussion of economic target costs. Briefly, these are the differences between the costs for LWRs and the expected larger costs for early LMFBRs. These costs would need to be absorbed by industry and/or government to bring these early LMFBRs on line on a cost competitive basis.

These cases were postulated to study the effects of rapid acceleration of the LMFBR program. These plans cannot be considered as viable since they would require impractical acceleration in the research and development program, permit little or no transmission of experience from project to project and transfer much of the risk inherent in the LMFBR program from the government to the private sector--a risk not likely to be accepted by industry. Nevertheless the effect of these program strategies if they could be successfully prosecuted would be to increase the program costs from $4 to $5 billion dollars while the benefits would increase by up to $15 billion because of early introduction of the CBR-1.

In essence, Plan 5 would eliminate the PLBR phase and start design of CBR-1 five years before CRBRP goes critical. Thus, CBR-1 would be well in the construction phase before CRBRP could provide any operational information. The transmission of experience from CRBRP to CBR-1 would therefore be minimal. In addition, the PCTF would be eliminated from the program, increasing the risks as discussed under Plan 2.

Plan 6 goes further and examines the situation in which both CRBR and PLBR-1 as well as PCTF are eliminated from the program and only FFTF experience would be available to the designers and constructors of CBR-1. It would of necessity have to rely heavily on foreign technology including the use of foreign components. This would reduce to a large extent the benefits gained from involving the U.S. industry closely in the program.

With regard to the higher risk involved in the accelerated cases, it is conceivable that in order to achieve any benefits of accelerating the program as shown in plan 4 or 5, or in proceeding directly to a commercial plant as in plan 6, the government might have to provide guarantees on the completion of the fuel cycle.

4. TREATMENT OF UNRESOLVED ENVIRONMENTAL ISSUES

a. Safety Program

The LMFBR safety program is of significant importance to the breeder reactor development effort. Sufficient analytical and experimental experience has been gained to allow the design of LMFBRs with the conservatism necessary to meet licensing requirements. However, there exists enough uncertainty in recriticality energetics, limiting core involvement, radiological source terms and containment features to warrant a requirement for excessive conservatism in design features to compensate for these uncertainties in knowledge.

There are two acceptable courses for dealing with these issues. One is to rely upon the experience gained as successive plants are designed, built and operated to gradually eliminate the uncertainties and remove the excessive conservatism in design. The other course is to mount a safety program to resolve these uncertainties in a minimum amount of time and thus maintain the LMFBR design on a sound basis with regard to safety without unnecessarily conservative design features. The second course has been used in the analysis of all the alternative LMFBR Program plans.

The discussion in Section III B and the analysis provided in Section I.4A indicate that the issues could be resolved on a more expeditious basis with the addition of a Safety Research Experimental Facility (SAREF) to currently existing safety facilities. With SAREF, confirmation of analytic and experimental data relative to the existing safety uncertainties could be resolved by 1986. Thus commercial reactors for which design starts in 1986 or later, could be constructed without unnecessary conservatism in safety design.

b. <u>Waste Management Program</u>

The major waste management issue is the unavailability of an accepted method for removing and segregating high-level and transuranium radioactive wastes from man's environment for the long time periods required for these wastes to decay to safe levels. Because of this, it has been suggested that the LMFBR Program should be delayed until a definitive method for permanent disposal of high-level radioactive wastes has been established. This problem is not unique to the LMFBR fuel cycle but must be resolved for the LWR or other nuclear fuel cycles before there is a requirement for disposal of high-level and transuranium wastes for the LMFBR fuel cycle.

The key element of the waste management program which has a bearing upon the LMFBR fuel cycle is the availability of a geologic disposal pilot plant. Programs are underway to develop such a plant for demonstrating safe geologic disposal by 1983, well in advance of requirements for the LMFBR Program, to meet the requirements associated with the LWR fuel cycle and the wastes resulting from the production of nuclear weapons. Since disposal of high-level radioactive waste from LMFBR fuel reprocessing plants will not be required until 12 years after start-up of an

LMFBR, the earliest time that a geologic disposal facility would be required for high-level wastes would be in 1999 for the prototype large breeder, or the year 2000 for the first commercial breeder. However, a geologic disposal facility could conceivably be needed as early as 1996 for disposal of significant amounts of transuranium wastes associated with the LMFBR fuel cycle. Since it is expected that the geologic disposal pilot plant might be converted to a full-size facility if it proves successful, there does not appear to be any constraint on the LMFBR Program imposed by disposal requirements for high-level or transuranium radioactive wastes.

c. <u>Safeguards Program</u>

The basic mission of the ERDA safeguards program is to develop and design cost-effective systems for all fuel cycle facilities and transport. Credible application to a particular future fuel cycle of technologies and methodologies which evolve from the safeguards development program requires firm information on the characteristics of future fuel cycle facilities, in particular the reactor plants and the fuel fabrication and reprocessing facilities. Given this kind of information, feasible safeguards systems can be synthesized, their effectiveness can be evaluated, and a management decision can be made.

Safeguards development includes consideration of measures which can be taken to minimize or reduce the harmful consequences of postulated successful adversary actions against a fuel cycle. Section III C discusses a number of such measures, and indicates an approach to determining their effectiveness in reducing overall risks.

It is prudent that a safeguards development program also make provision for long-term demonstrations of the safeguards technologies and systems projected for widespread use, in order to provide for continuing assessment of their effectiveness in a commercial environment. Although such demonstrations should be of considerable value in refining predictions and judgments, they are not prerequisite to a management decision on the safeguards-related acceptability of a commercial fuel cycle for the future.

The ERDA program for LMFBR safeguards described in Section III C is configured to provide the information necessary for a management decision in the early to mid-1980's, with long-term demonstrations starting throughout the 1980's. This timing applies to 7 of the 8 LMFBR Program plans which have been examined. In the case of plan 7, the decision date is 1995 because design information on large LMFBR reactor plants is not available until much later in that case.

d. Health Effects Program

The primary health effects issue for the LMFBR Program is the evaluation of the potential hazard resulting from the use of plutonium. It should be noted that the toxicity of plutonium had been recognized long before the outset of the LMFBR Program, and extraordinary measures have been taken to isolate plutonium from the environment. In the absence of any significant observed human health effects which can be related to plutonium exposure, a variety of extensive biomedical studies are being conducted in order to define both effects and mechanisms resulting from the internal deposition of alpha-emitting radionuclides such as plutonium. It is not realistic to attempt to project a fixed point in time at which the entire plutonium toxicity issue will be definitively resolved to everyone's satisfaction. However, a major program is underway to obtain additional information on plutonium toxicity. The data base is constantly expanding and various components of the studies are expected to be completed over the next 3 to 20 years.

A major point of contention raised in comments on the PFES has been the "hot particle" hypothesis. Some individuals have predicted that "hot particles" deposited in the lung might lead to greater cancer risks than those predicted using commonly accepted methodology. The Los Alamos Scientific Laboratory, the National Council on Radiation Protection and Measurements, the National Radiation Protection Board of the United Kingdom, and the Medical Research Council of the United Kingdom have independently analyzed the "hot particle" hypothesis, and each has found it unsupportable. The National Academy of Sciences is also examining this hypothesis at the request of both ERDA and EPA, and the results of its study are expected in the near future. Animal studies of the "hot particle" hypothesis should be completed in 5-10 years, leading to anticipated resolution of this matter by 1985.

5. AVAILABILITY OF INFORMATION FOR ADMINISTRATOR'S DECISION POINTS

Table S-1 presents possible decision dates for the three key program elements described above -- plant experience, base program and environmental issues -- for the reference program and the seven alternative program plans analyzed. As described above, in order for the Administrator to make his determination, all three program elements must have received sufficient attention to permit confident predication that the technology will be available when required. Inspection of that Table reveals that the decision date varies from plan to plan and the constraints on the decision also vary. The year in which sufficient information is available to permit the Administrator to make his decision for each of the programs considered is listed in Table S-2. It can be seen that the reference plan and alternative plans 2, 4 and 5 permit the earliest date -- 1986 -- in which the Administrator can determine the acceptability of LMFBR technology for widespread commercial deployment.

6. URANIUM RESOURCE EVALUATION

The question of how much relatively high grade uranium ore may exist and eventually be discovered in the U.S. is not of great importance to the LMFBR per se, because the currently available resource is already sufficient to support a large LMFBR industry for over a century. The question of the extent of uranium resources arises, however, as a result of contentions that the LMFBR is not needed, or at least not needed until sometime in the next century.

Basically, it is argued that ERDA estimates grossly understate potential uranium resources because they are based on information gathered only from western producing areas and their environs, which, constitute only a fraction of U.S. land areas. It is contended that an abundance of economic uranium exists and is awaiting discovery in the relatively unexplored regions of the U.S. On this basis, it is presumed that U.S. uranium resources are sufficient to support needed growth in non-breeder reactor capacity through the end of the century and beyond, at which time alternative sources of electricity (e.g., solar or fusion) may be available in lieu of the LMFBR.

ERDA's National Uranium Resource Evaluation program (NURE - discussed in Section III E of this Volume) which has been in progress for about two years, is designed to provide a systematic and comprehensive survey of the conterminous United States and Alaska by 1980. Within the capability of the currently available exploratory techniques, NURE is expected to identify localities in the U.S. which appear favorable for intensive uranium exploration (drilling), and to provide at least a

Table S-1

KEY PROGRAM ELEMENT DECISION DATES

Plan	Plant Experience	Base Program	Environmental Issues: Safety*	Safeguards	Waste Management	Health Effects**
Reference	1986	1986	1986	1982	1985	1985
1	1993	1986	1986	1982	1985	1985
2	1986	1986	1986	1982	1985	1985
3	1987	1986	1986	1984	1985	1985
4	1986	1986	1986	1982	1985	1985
5	1986	1986	1986	1982	1985	1985
6	1991	1986	1986	1982	1985	1985
7	1993	1986	1986	1995	1985	1985

*Not a requirement for licensing or operating LMFBRs. Has a bearing upon commercial competitiveness of system, i.e., whether excessive design conservatism and consequent expense can be removed.
**Date by which "hot particle" issue (see Section III G) is expected to be resolved.

Table S-2

ALTERNATIVE PROGRAM DECISION DATES

Plan	Year
Reference	1986
1	1993
2	1986
3	1987
4	1986
5	1986
6	1991
7	1995

rough idea of how much uranium may reside in such localities. Such information will provide a reasonable basis for estimating a probable upper limit on the amount of potential uranium resources that may be available in the U.S. in future years.

NURE can provide insight on the industrial capability to produce uranium at needed rates. ERDA has a continuing program for projecting production capability from ore reserves and potential resources. The rate at which the industry can mine and mill uranium is the single, most important factor in determining the size of the non-breeder reactor industry that can be supported by U.S. uranium resources.* This rate depends, at any given time, upon how much uranium has been located and developed to the point of mining. In general, a given rate of annual production requires the output of a number of mines collectively containing about 10 times as much U_3O_8 as the annual rate.

For the past four years, despite greatly increased drilling, industrial exploration has produced new reserves which barely offset production in those years. Unless increased industrial exploration results in a much larger discovery rate, the industry may be unable to achieve and sustain the production rates required for projected uranium demand in 1985 and beyond. The uncertainty involved here is one of the bases for the conclusion that prudence dictates the early commercialization of the LMFBR.

More specifically, based on existing uranium reserves and rates of addition to these reserves (by industrial exploration) over the past four years, there is insufficient basis for assuming that uranium production capability will be adequate to support nuclear power in the 1990's without the breeder. This picture could, of course, change if greater success were achieved in exploration.

7. ALTERNATIVE TECHNOLOGY OPTIONS

The major alternatives to the LMFBR in providing long-term "inexhaustible" energy resources have been identified by ERDA as fusion energy and solar energy. These alternatives have been discussed in detail in Section III H of this Statement. That Section identifies key points in each program at which decisions can be made as to the feasibility of the options.

*Of course, mining and milling of uranium reserves will not solve the problem unless adequate uranium enrichment capacity is available. Current capacity is not sufficient to support an expanded non-breeder industry and the problem of providing increased enrichment capacity must be resolved.

If one considers successful construction, licensing and operation of a large demonstration plant as the point at which a managerial decision could be made on the acceptability of each option for widespread commercial deployment, it can be seen from reference to Table S-3 (which summarizes key decision dates in the fusion program) that the decision on commercial deployment of fusion energy could conceivably be made in the mid-1990s if the goals of the fusion program are achieved. Using the same logical approach, Table S-4 shows that the four solar energy options could conceivably reach the decision point on commercial acceptability in the mid to late 1980s. Achievement of the key decision points assume vigorous and successful prosecution of the respective research and development programs and is independent of the prosecution of the LMFBR Program. Similarly, these decision points have no effect on the achievement of the LMFBR decision points.

Table S-3

KEY DECISION POINTS - FUSION ENERGY PROGRAMS

Program	Decision Points	Calendar Year
Magnetic Confinement	Fusion energy from Tokamak Fusion Test Reactor	1982
	Electrical energy from Experimental Power Reactors	1985-1990
	Initial operation of commercial scale Demonstration Power Reactor	1997
Laser	Scientific breakeven	1980-1981
	Net energy gain	1981-1983
	Operating test system	mid-1980's
	Demonstration plant	mid-1990's

Table S-4

KEY DECISION POINTS - SOLAR ENERGY PROGRAMS

Energy System	Decision Points	Calendar Year
Wind Energy Conversion	Experimental units -	
	100-KWe	1980
	MWe scale	1981
	Multi-unit demonstrations-	
	10-MWe pilot plant	1982
	100-MWe demonstrations	mid-1980's
Solar Photovoltaic		
	Large Scale Production -	
	silicon arrays	1985
	thin - film cells	1990's
	100-MWe installed capacity	late 1980's
Solar Thermal Conversion	Central receiver plant -	
	pilot	1981
	demonstration	1985
	Distributed collector plant -	
	pilot	1981
	demonstration	1985
	Solar total energy system -	
	pilot	1981
	demonstration	late 1980's
	Hybrid solar thermal -	
	pilot	1982-1983
	demonstration plant	late 1980's
Ocean Thermal Conversion	25-MWe floating power plant	1986
	100-MWe demonstration power plant	1987

SECTION I

LMFBR PROGRAM OPTIONS

AND THEIR COMPATIBILITY WITH THE

MAJOR ISSUES AFFECTING COMMERCIAL

DEPLOYMENT

I.1 INTRODUCTION

This section provides an evaluation of the range of options available to the Administrator for structuring the LMFBR Program (I.3) and the compatibility of those program options with the timely resolution of the major environmental issues -- reactor safety, safeguards, waste management and health effects -- involved in widespread LMFBR deployment (I.4).

I.2 SUPPORTING ENVIRONMENTAL ISSUE DATA

The major environmental issues involved in widespread LMFBR deployment are discussed in detail in the following subsections of Section III.

- Reactor Safety (III B)
- Safeguards (III C)
- Waste Management (III D)
- Health Effects (III G)

I.3 AN EVALUATION OF ALTERNATIVE LMFBR PROGRAM PLANS

1. INTRODUCTION

In pursuance of its responsibilities to conduct the LMFBR Program in an optimum, expeditious and cost-beneficial manner, the Division of Reactor Research and Development (RRD) has prepared program plans which have served to guide the research and development program. These plans have been updated and revised as the program has progressed and as successive stages in the development program have been reached. The first plan[1] was formulated and published in 1968 to provide a better focus for the research and development program. The plan was reissued in a second edition[2] in 1973, reflecting progress achieved in the interim period and adding emphasis to those areas of the program crucial to the demonstration phase.

A review of the program in 1974 resulted in a consensus that basic technology areas were being adequately covered, but that a deficiency existed in large sodium component development and plant experience. The critical program elements were identified as those related to reducing uncertainties in LMFBR plant cost and component performance to levels acceptable to utilities in purchasing these plants and acceptable to reactor manufacturers in marketing the plants. In accordance with the conclusions of this review a program revision was announced by the Director, Division of Reactor Research and Development, in the FY 1976 Authorization Hearings before the Joint Committee on Atomic Energy, March 11, 1975. The program revision reflected an increased emphasis on component development, validation and LMFBR plant experience.

The Administrator's request for a further examination of progrommatic alternatives has now led to an evaluation of 8 alternative LMFBR Program plans which have been selected to illuminate trade-offs among development costs, technical and financial risks and national benefits.

The environmental impact of the base program was examined in March 1974.[3] Since the current base program does not vary in any substantial degree from the program examined at that time, and does not vary in scope for any of the seven alternative programs and the reference program, the evaluation performed at that time is believed to still apply. During that review the environmental impacts of base program activities at the eight major centers and other sites involved in the base program as well as transportation activities were examined and documented and were found not to be significant. It is recognized that further evaluation from time to time will be required as the program proceeds to assure that the determination as to the environmental acceptability of the base program still applies.

Insofar as major new facilities in the base program and the demonstration program are concerned, many of these have specific, localized environmental impacts which therefore require site-specific environmental statements. In this regard, a site-specific environmental statement has already been issued on the Fast Flux Test Facility.[4] A site-specific environmental statement is now in preparation on the Clinch River Breeder Reactor Plant. Similar site-specific statements will be prepared for each new major program facility.

2. STUDY APPROACH

The evaluation focuses primarily on the timing and scope of program elements related to component development, validation and LMFBR plant experience, and the consequent changes necessitated in the base research and development program.

These program elements are:

(a) The Clinch River Breeder Reactor Plant (CRBRP). This plant, currently in the detailed design stage, will have three heat transport loops of about 325 MWt each, giving a rated plant capacity of about 350 MWe.

(b) The Prototype Large Breeder Reactors (one or two, designated PLBR-1 and PLBR-2). Conceptual design efforts for the PLBR(s) have recently been initiated. Aside from financial and institutional aspects, there is little distinction between the PLBR and the commercial breeder reactors (CBRs) assumed to follow. Loop and component ratings of the PLBR and CBR are assumed identical. While a PLBR may be limited to two or three loops, the CBRs may have two, three, or four loops, as economics dictate. Assumed plant ratings of PLBR(s) and CBRs are between 1000 and 2000 MWe.

(c) The Sodium Component Test Installation (SCTI), an existing non-radioactive sodium test facility at the Liquid Metal Engineering Center (LMEC), Canoga Park, California. The SCTI is currently rated at 35 MWt, and will be upgraded to 70 MWt for partial-capacity tests of CRBR intermediate heat exchangers and steam generators.

(d) The Sodium Pump Test Facility (SPTF), an existing non-radioactive test facility at LMEC. The SPTF is presently limited to 20,000 gpm. The current test schedule includes testing of FFTF (14,500 gpm) and CRBR (33,000 gpm) pumps, and the first large General Electric electromagnetic pump. (CRBR pump testing will be at partial flow.) Current program plans call for upgrading the SPTF to about 100,000 gpm for full scale testing of large LMFBR pumps.

(e) The Plant Components Test Facility (PCTF), a proposed 300 MWt non-radioactive facility whose primary mission would be to test LMFBR heat exchange equipment larger than could be accommodated in SCTI. Over the past year and one half, several configurations of this facility have been proposed and evaluated by the LMFBR technical community.

The 70 MWt SCTI and the 100,000 gpm SPTF are the only program elements cited above which appear in each of the eight program strategies which have been evaluated. The existence and timing of the other elements are varied in order to provide a basis for evaluation of differences in program "cost" and "risk." In all strategies, program benefits are considered to start at the time of CBR-1 criticality. The terms "cost," "risk," and "benefit," as used in the study, are defined later in this discussion.

The transmission of experience to successive plant projects is a major goal in planning and executing a coherent program. If, for example, there is no information transfer from one plant project to its successor, then the value of the earlier plant as a technological bridge is minimal. The scope and usefulness of information transferred, of course, depends on the relative timing of successive plants. Maximum data transfer occurs and scale-up risks are minimized when projects are adequately spaced in a sequence allowing milestones of one project to be achieved before a follow-on project is initiated. However, too wide a separation in time between successive projects runs the risk of loss of momentum in the program, and dispersal of skilled design and construction teams as well as managerial organizations. Also, the longer time involved in the spacing of elements in a program, the greater the base support R&D cost and the longer the delay in receiving the initial benefits of the program, correspondingly reducing the cost-benefit advantage.

There are three major categories of experience which can be transferred from one project to a follow-on project. These are:

- experience from the design, licensing, and procurement process
- prototype testing (in a non-nuclear test facility)
- operating experience

With these considerations in mind, seven alternative program plans were considered and were compared with the reference plan. Table I.3-1 compares these plans.

Table I.3-1

REFERENCE AND ALTERNATIVE LMFBR PROGRAM STRATEGIES

	Reference R	W/O CRBR #1	Reference W/O PCTF #2	Delay #3	Accelerated #4	High Accel. w/CRBR #5	High Accel. W/O CRBR #6	Sequential #7
PLANT EXPERIENCE					CALENDAR YEAR			
FFTF Critical	79	79	79	79	79	79	79	79
CRBR Start Design	73		73	73	73	73		80
Start Construction	76	None	76	77	76	76	None	83
Critical	83		83	84	83	83		90
PLBR-1 Start Design	78	78	78	80	77			91
Start Construction	81	83	81	83	80	None	None	94
Critical	88	90	88	90	87			2001
PLBR-2 Start Design					79			
Start Construction	None	None	None	None	82	None	None	None
Critical					89			
CBR-1 Start Design	83	85	83	86	80	78	78	2002
Start Construction	86	88	86	89	83	81	81	2005
Critical	93	95	93	96	90	88	88	2012
COMPONENT TEST FACILITIES								
SCTI (70 MW_t)	78	78	78	78	77	79	79	85
SPTF (100,000 gpm)	79	79	79	79	78	79	79	92
PCTF	81	81	None	81	None	None	None	94

Reference Plan

The reference plan is designed with a modest overlap in project schedules in order to assure a reasonable degree of transmission of experience. This plan provides for criticality of the Fast Flux Test Facility (FFTF) in 1979, and for CRBRP construction beginning in 1976 with criticality achieved in 1983. The first large LMFBR - designated PLBR-1 - would enter the detailed design phase in 1978, two years after construction of CRBRP begins. This date corresponds to the end of the PLBR conceptual design studies which began in October 1975 and is approximately two years after CRBRP construction starts. Construction of the PLBR would then begin in 1981 with criticality scheduled for 1988.

Design work on the next large breeder reactor - designated Commercial Breeder Reactor 1 (CBR-1) - would start approximately two years (1983) after construction of PLBR starts. The designation of this plant as CBR-1 rather than PLBR-2 implies that this is the first LMFBR project initiated by reactor vendors and utilities, perhaps with government financial assistance. Successive commercial plants are assumed to rapidly follow CBR-1, with some of these also possibly receiving government assistance, but evolving into a solely commercial industry.

CRBRP steam generator tests in SCTI would begin in 1978 along with CRBRP pump tests in SPTF. Expansion of SPTF to test PLBR pumps would be completed in 1979 and construction of the PCTF for testing PLBR steam generator modules would be finished in 1981.

Although construction of PLBR starts before operation of CRBRP, the design, licensing and procurement process in PLBR benefits from the completed design and licensing activity in the CRBRP project (design of PLBR occurs after award of CRBRP construction permit), and from the concurrent CRBRP procurement and component testing activities.

The necessary design, licensing and operating experience will be available from the CRBRP and PLBR projects to begin construction of CBR-1 prior to completion of PLBR. When CBR-1 construction begins in 1986, three years of operating experience will be available from CRBRP, and the fabrication and testing of PLBR components will have been completed. (Large components in CBR-1 will be of the same size as those used in PLBR.) Furthermore, the design, procurement and licensing phases of PLBR will have been completed and the PLBR construction permit will have been issued. Delaying the sequence until PLBR operating experience becomes available would be counterproductive because the teams of designers, engineers, and test facility operators would have to be demobilized and mobilized again resulting in delays and the loss of experienced personnel. These delays would in turn increase program costs and reduce the economic benefits associated with timely LMFBR introduction.

Plan 1

In the past several years the objectives and validity of CRBRP have been challenged on the basis that CRBRP will not be prototypical of the large-size LMFBRs of commercial interest, that the 200-400 MWe size range has already been demonstrated by the French program and that better use would be made of the CRBRP funds in resolving environmental and safety issues.

Plan 1 was defined in order to assess the impacts of eliminating CRBRP from the program. An attempt was made to adhere as closely as reasonable to the reference program so that the effect of eliminating CRBRP could be clearly seen. However, it became apparent that the reference plan milestones subsequent to CRBRP would have to be changed. Without the CRBRP licensing precedent and the experience gained in designing, fabricating and testing CRBRP component prototypes, the PLBR and CBR-1 operational dates will most likely slip at least two years, to 1990 and 1995, respectively. Contributing to this delay would be: (a) the demobilization of the engineering teams (both reactor design and component vendor); (b) the refocusing of the base technology and safety programs to obtain the necessary supporting data to extrapolate to large plant sizes (much greater than normal engineering experience would dictate); (c) delays in obtaining statistical fuel performance, breeding ratio, and core performance data; (d) greater difficulties and delays in achieving resolution of licensing problems; and (e) increased construction time resulting from loss of experience in constructing CRBRP.

Plan 2

Plan 2 is identical to the reference plan except that the PCTF is not included. The costs and risks of this plan when compared with those of the reference plan provide a basis for estimates of the value of PCTF to the program. Elimination of PCTF represents a substantial change in program philosophy in that it shifts the task of proving out plant components from testing facilities to the operating power plant itself.

Delayed Plans

Plans 3 and 7 include the same elements as the reference plan, but on delayed time schedules. In both cases, CBR-1 is correspondingly delayed. These strategies were selected in order to permit evaluation of tradeoffs between reduced program risks (due to increased experience transfer) and reduced program benefits (due to delay in CBR-1 operation).

In plan 3 the startup of CRBRP is delayed one year, the startup of PLBR-1 two years and the startup of CBR-1 three years. The component test program scope and schedule are identical with those of the reference plan. This approach could reduce risks by allowing more time for experience to flow between plant and test projects. The delays would, however, result in reduced benefits of the breeder to the Nation.

Plan 7 is a sequential plan in which design of CRBRP awaits the first year of operation of FFTF, design of PLBR awaits the operation of CRBRP and so on. The testing facilities are also significantly delayed: SCTI until two years after CRBRP construction begins in 1983, SPTF until two years before PLBR construction begins in 1994 and PCTF until 1994. This plan is sequential in terms of LMFBR plant experience to reduce risks. However, earlier availability of testing facilities could also be effective in reducing risks. In this sequential plan, the component tests in PCTF parallel actual fabrication of units for PLBR as they do in the reference plan.

Accelerated Plans

Plans 4, 5 and 6 represent accelerations in the timing of program elements, as compared with the reference plan. It is postulated that these accelerations would permit earlier CBR-1 availability, thus enhancing program benefits at the expense of increased risk through diminution of information transmitted from one project to the next.

Plan 4 advances PLBR by one year, adds a second PLBR for startup two years after the first, and accelerates CBR-1 by three years. SCTI and SPTF schedules are moved up by one year, but PCTF is deleted from the plan. PLBR-2 is designed as a near duplicate of PLBR-1 so as to take as much advantage as possible of learning curve effects to reduce costs. Deletion of PCTF, as in plan 2, changes the program philosophy away from full-size prototype component testing prior to installation in the nuclear power plant.

Plan 5 is a highly accelerated plan which deletes the PLBR reactors and includes a CBR-1 reactor on the same schedule (1988 startup) as was specified for the first PLBR in the reference plan. As in the accelerated plan, PCTF was deleted. In effect, since the first CBR plant is defined as the first of a succession of commercial LMFBRs, this plan would accelerate the commercialization of the breeder by five years. The risks inherent in this more rapid commitment are even greater than for plan No. 4 since no experience is gained from design and construction of PLBR-1 and 2.

Plan 6 is identical to plan 5 except that CRBRP is also deleted. This plan as well as the previous plan might not accomplish the objective of making the follow-on commercial breeders available on the accelerated schedule intended because of the higher risks and commercial costs inherent in these plans. Nevertheless the same rate of commercial breeder additions, accelerated by five years, as in the reference plan was assumed in both plans 5 and 6. Risks and costs were then evaluated on this basis. Heavy reliance on foreign technology would probably be required to achieve this plan with the consequent loss of a major objective of the program, the development of domestic capability to develop and sustain an LMFBR economy.

3. COMPARISON OF COSTS, RISKS, AND BENEFITS OF ALTERNATIVE LMFBR PROGRAM PLANS

An attempt was made to quantify program costs, risks, and benefits for the seven alternative strategies and compare these costs with the reference plan. Costs include developmental costs to the Government plus non-economic portions of the capital costs of the first few commercial LMFBRs. Benefits are the national cumulative power cost savings, through the year 2020, associated with the LMFBR. Risks are those associated with plant component scaleup to sizes of commercial interest. Two elements of risk-cost were quantified: the cost of rework when a component fails; and the delay-cost, or loss of national benefits due to program delay, when a component fails.

Since the risks considered were restricted to ultimate component performance, principally large steam generators and pumps, the analysis is a partial risk analysis. Risks associated with licensing, test facility costs and schedule, fuel performance, etc., were not examined quantitatively.

Further, there are large inherent uncertainties in the component risk analysis. The methodology used rested ultimately on the collective judgments of design engineers and the results are inherently subjective. Also, the structure of the calculation tends to underestimate risks. A perfect "fix" (but with associated cost and program delays) is assumed available at any time in the program that a component failure occurs. In other words, the "fix," e.g., an alternative design, contains no risk.

Similarly, there are large uncertainties in the costs and benefits. The cumulative national benefit is a function of the ore resource base and its cost structure including enrichment costs, the future electrical demand, and the costs of the LMFBR and its competitors--with large uncertainties involved in each factor. The differential LMFBR construction costs (non-economic portion) are sensitive to the same factors.

The analysis presented here illustrates a conceptual framework, a framework which can be applied in future program evaluations. Future evaluations will quantify risks in areas other than components. As more insight is gained in the PLBR conceptual design efforts, uncertainties in the quantification of component risks and the capital cost of large LMFBRs can be reduced. Similarly, uncertainties in cumulative benefits will be reduced as more reliable estimates of the uranium ore resource base are obtained.

Table I.3-2 summarizes the development program costs associated with the reference and seven alternative strategies. The first column gives total program costs for the reference plan in 1977 dollars. The budget structure shown here differs from the familiar ERDA Budget and Reporting System format, and was formulated to illuminate the principal considerations of the study. For purposes of the study:

(1) Fuel recycle program costs are included under the category "Base Support after CBR-1";
(2) The PLBR cooperative project cost of $1.77 billion includes potential government contributions to construction costs of both PLBR(s) and CBR-1; and
(3) An account (Residual Construction) has been included to provide for potential government participation in construction costs beyond CBR-1 ($2.86 billion).

The Base Program costs given here are consistent with other RRD estimates, except that construction and modification costs for principal component test facilities (PCTF, SCTI, SPTF) are shown separately. Also, Base Program costs are allocated to specific plants through CBR-1, and to the group, CBR-2 through 100. Generic programs, applicable to the entire future LMFBR economy, e.g., fuel recycle and advanced fuel development, are included in the latter category.

The cooperative construction project costs for PLBR and follow-on large LMFBRs are taken to be differential costs of these projects, i.e., the capital costs equivalent

Table I.3-2

RELATIVE COSTS OF THE REFERENCE AND ALTERNATIVE PROGRAM PLANS
(Billions of Dollars - 1977)

		RELATIVE TO REFERENCE STRATEGY (R)						
	REF (R)	W/O CRBR (#1)	REF W/O PCTF (#2)	DELAY (#3)	ACCEL. (#4)	HI-ACCEL. W/CRBR (#5)	HI-ACCEL. W/O CRBR (#6)	SEQUEN. (#7)
COSTS (Undiscounted)								
PCTF, SCTI, SPTF Construction	0.34	0	-0.29	0	-0.29	-0.29	-0.29	0
FFTF, CRBR Construction	1.34	-1.01	0	0	0	0	-1.01	0
PLBR(s), CBR-1 Construction	1.77	-0.1	0	-0.1	+0.6	-0.73	-0.73	-0.48
Residual Construction	2.86	-0.7	0	-0.74	+0.33	+6.6	+6.6	-2.86
Base Support thru CBR-1	3.73	+0.12	0	+0.12	0	0	-0.19	+0.49
Base Support after CBR-1	1.69	0	0	0	0	0	0	0
Misc. Facilities, Const. & Op.	2.65	0	0	0	0	0	0	0
TOTAL	14.38	-1.69	-0.29	-0.72	+0.64	+5.58	+4.39	-2.85

to the power cost differential between LMFBRs and LWRs. Uncertainties in these estimates are large. More reliable estimates will be available as the LMFBR target design projects proceed, and as greater confidence is gained in estimates of the uranium ore resource base. These costs are included here for conceptual reasons, and for the purposes of this analysis they are treated as program costs. While inclusion of these costs tends to imply that the government will cover these costs, it is premature to state that this is the government's intention. Other institutional and financial arrangements, e.g., spreading the initial non-economic costs over a large number of utility companies, may be sought as specific cooperative contracts are negotiated.

Plan 1

Plan 1 omits CRBRP from the reference LMFBR Program plan. This would require a direct transition from FFTF to PLBR-1 without the benefit of experience from CRBRP and would most likely increase the construction and licensing periods for CBR-1. These factors would delay the criticality of CBR-1 by two years and would reduce the discounted national benefits of the LMFBR Program by $6 billion. Elimination of CRBRP would reduce the overall cost of the program by $1.7 billion as compared to the reference plan (See Table I.3-2). However, the loss of experience which would have been achieved through design, construction and operation of CRBRP is estimated to add $1.5 billion in risk to the program. Because of the greater risks inherent to this plan, it is expected that greater government support would be required for PLBR-1 than for the reference plan.

Plan 2

Plan 2 is identical to the reference plan except that PCTF has been omitted. The national benefits associated with the plan are identical to those of the reference plan since the introduction date of the commercial LMFBR, i.e., the availability date of CBR-1, is the same in both cases. The risk assessment indicated that building PCTF would result in a risk reduction in the range of $500-1,000 million. Thus the construction cost of PCTF (about $300 million) is more than recovered.

Plan 3

In Plan 3 risk reduction is accomplished by delaying the plant sequence while holding the test program fixed. The level of risk relative to the reference plan is in the range of $500-1,000 million. However, the introduction date of the CBR-1 is delayed three years, with a benefit penalty of up to $9 billion. A savings of about $700 million in program cost is accomplished, due largely to a reduction of the construction cost differential between LMFBRs and LWRs.

Plan 4

In Plan 4 national cumulative benefits are maximized by advancing the introduction date of the CBR-1 by three years. Potential additional benefits ranging up to as high as $9 billion could be achieved. This plan omits PCTF and includes an additional PLBR. Additional construction differential costs of about $1 billion are incurred because the LMFBR target cost (parity with total LWR power costs) is lower. Additional risks of $200-600 million are also incurred due to the absence of PCTF and the diminished flow of experience among successive plant projects.

Plan 5

In Plan 5, both PCTF and PLBR are omitted. Nevertheless, the availability date of CBR-1 and the national LMFBR capacity growth schedule is advanced by five years. In effect the risks inherent to PLBR in Plan 2 are transferred from the government to the private sector, and magnified by the multiplicity of large commercial plants. It is debatable whether the private sector would accept these risks. Thus the assumed growth of LMFBR commitments following CBR-1 is probably grossly exaggerated. If this plan were to be implemented on the target schedule, then substantial additional benefits (relative to the reference plan) would accrue--as high as $15 billion. A more likely scenario is that the commercial growth schedule would slip back to that assumed in Plan 1, with a resulting elimination of added benefits. Substantial added costs in Plan 5 are incurred due to increased "non-economic" differentials between the LMFBR and the LWR, due to the LWR's lower fuel cycle costs in the earlier period of LMFBR introduction.

Plan 6

Plan 6 is identical to Plan 5 except that CRBRP is omitted. However, in this case the risks and difficulties in implementing the commercial construction would be even greater due to the complete lack of plant experience except for FFTF.

For example the increased risk due to lack of steam generator experience alone is estimated to be of the order of $2 billion. Thus the additional risk incurred in this plan clearly exceeds the CRBR cost estimate. Use of foreign technology might reduce the risk at the expense of failing to develop a domestic engineering and manufacturing capability.

Plan 7

In Plan 7 LMFBR demonstration and prototype plants are scheduled such that complete transmission of data and experience occurs among successive plant projects. This is a minimum risk approach, and the risk reduction affected (relative to the reference plan) is in the range of $1-3 billion. Substantial savings also accrue in plant construction cost differentials between LMFBRs and LWRs. However, the national benefits of the LMFBR option through the year 2020 are essentially eliminated since the introduction date slips 19 years relative to the reference plan. This is equivalent to $50-60 billion in foregone discounted benefits.

4. BASE PROGRAM CONSIDERATIONS

Review of the base research and development program has revealed that the controlling element in the program is the development of a technically and economically adequate fuel reprocessing and recycle system. By 1986 all the design work for a LMFBR fuel reprocessing hot pilot plant and its equipment should be finished and construction should be well along. In addition, industry should be making contributions, with ERDA support, to a conceptual commercial plant study and to large scale component development and testing. These combined activities will provide data from which early projections of LMFBR fuel cycle economics and overall breeder power plant potential for commercialization can be assessed.

It has been concluded that an adequate basis will exist to predict the successful completion of a safe, reliable, and economical fuel cycle by 1986. At that time, equipment design, development, and cold engineering operation will have been completed on the hot pilot plant. Operation of the hot pilot plant will verify, using a statistically significant quantity of fuel, the behavior of the fuel during processing and will permit, through material balance measurements, the identification and location of all significant fuel materials throughout the plant. On certain large, key components, engineering tradeoffs will provide a base of experience for the construction and operation of economical full-scale plants. It will serve as a key facility for evaluation and for demonstration of improvements in fuel reprocessing technology. Although this information developed from operation of the hot pilot plant will be important for design of the optimum fuel recycle plant, it is not considered necessary for the information to be developed prior to the decision on acceptability of LMFBR technology for widespread commercial deployment.

Another key element of the base research and development program is the development of advanced LMFBR fuels. The fuel development program objective is to provide a range of fuel options, so that the reactor designer can make a selection in 1986.

I.4 ANALYSIS OF THE RESOLUTION OF MAJOR ISSUES AND THE COMPATIBILITY WITH LMFBR ALTERNATIVE PROGRAM PLAN MILESTONES

INTRODUCTION

As mentioned previously, four major issues (safety, waste management, safeguards, and health effects) have been identified as requiring further resolution before a commitment to widespread commercial deployment of LMFBRs may be made. The question arises as to whether the time period required to resolve these issues is compatible with the schedules set forth in the program planning alternatives analyses discussed in Section I.3.

Accordingly a study has been performed on the compatibility of the program milestones directed at resolving these four major areas of concern with the milestones projected for the reference plan and the seven LMFBR alternative program plans. Table I.3-1 above shows the milestones for achieving design, construction and plant criticality for each of the eight plans reviewed. The analysis for each of the four major areas of concern follows.

I.4A SAFETY PROGRAM COMPATIBILITY WITH ALTERNATIVE LMFBR PROGRAM PLAN MILESTONES

An LMFBR, like any reactor, is a potential public hazard because of its inventory of Pu and of fission products. These must be confined to assure public safety. The safety program has the responsibility for developing a base of understanding and data which will permit reactor designers to provide assurance beyond confinement that these hazardous materials will not reach the environment and the public.

Completion of the safety program will permit substantial design flexibility relative to current practice, allowing greater confidence, as well as improved efficiency, and reduced costs and schedules. Safety input is required at the conceptual design stage to be effective. Therefore, the development of safety technology will substantially precede large scale deployment of the concept. Public acceptance must be established in addition to acceptance by the technical community.

The LMFBR safety program is discussed in great detail in Section II, 4.2.7 and Section III B of the Statement. No safety issues have been identified which, in the opinion of ERDA staff, would prevent design, construction and operation of safe and licensable commercial-size LMFBRs. However, there are three principal elements of the safety issue which are currently incompletely resolved and these impose design constraints on the LMFBR to assure its acceptability by regulatory authorities, industry and the public. The safety issue must be resolved so as to provide realistically conservative design and improve the economic competitiveness of large size breeder reactors.

The principal safety elements that have been identified are:

a) Recriticality Energetics

   It has been traditional in LMFBR safety discussions to ask what would happen if LMFBR fuel were suddenly compacted into a supercritical mass. The significance of recriticality energetics is that the induced power could, if achieved, constitute a challenge to the integrity of the primary system. Further, it constitutes perhaps the only effective means for generating a large scale radiological source term. Evidence to date indicates that none of the conditions required for such an event would be achieved in an LMFBR accident. Nevertheless, it is felt that further demonstrations are required.

b) Limited Core Involvement

   The basic characteristics of an LMFBR strongly tend to make accident consequences self limiting. There is good reason to believe that even serious accidents would be restricted to limited portions of the core. To the extent that convincing demonstration of this can be accomplished, the problem of accommodating the consequences of accidents are dramatically reduced. In addition to public safety, there is strong economic incentive to provide the assurance that core involvement would be limited to a portion of the core.

c) Radiological Source Term and Containment Features

There is no public hazard from a reactor other than that potentially associated with release of radioactive material. Many natural and engineered characteristics provide physical barriers to the release of radiological products. For an LMFBR, a number of features such as inherent sodium filtration and aerosol effects appear to offer dramatically larger inherent attenuation than is currently claimed. A program is underway to better define the source generation and attenuation factors achievable. Successful completion of this program will have economic as well as safety benefits in that containment features could be more realistically designed.

Final resolution of elements a) and b) could be most expeditiously and convincingly demonstrated by construction and operation of a new safety facility, the Safety Research Experiment Facility (SAREF). Design characteristics of this facility are under study and final determination in early 1976 of the design parameters would permit early start of construction. Other facilities* needed to resolve the elements of the safety issue are already in operation and providing needed information.

Because of the pervasive nature of the recriticality energetics issue and the complexity of demonstrating resolution of this issue in a series of non-integral experiments, a special purpose test of this problem has been studied. There may be merit in other potential special purpose tests such as a large scale short period fuel coolant interaction (FCI) test to demonstrate that there are no unexpected scale effects; or a molten fuel pool or debris bed coolability and post-accident heat removal (PAHR) demonstration may be desirable. Several approaches to special purpose tests may be considered, including use of foreign facilities, FFTF or EBR-II, or specially designed facilities. No decisions have been made as to the necessity for these additional facilities. Should studies and analyses show that such special purpose tests would accelerate the resolution of the safety issue, they will be added to the program.

*Fuel Failure Mockup (FFM), Sodium Loop Safety Facility (SLSF), Out-of-Pile Expulsion and Re-entry Apparatus (OPERA), Transient Reactor Test Facility (TREAT).

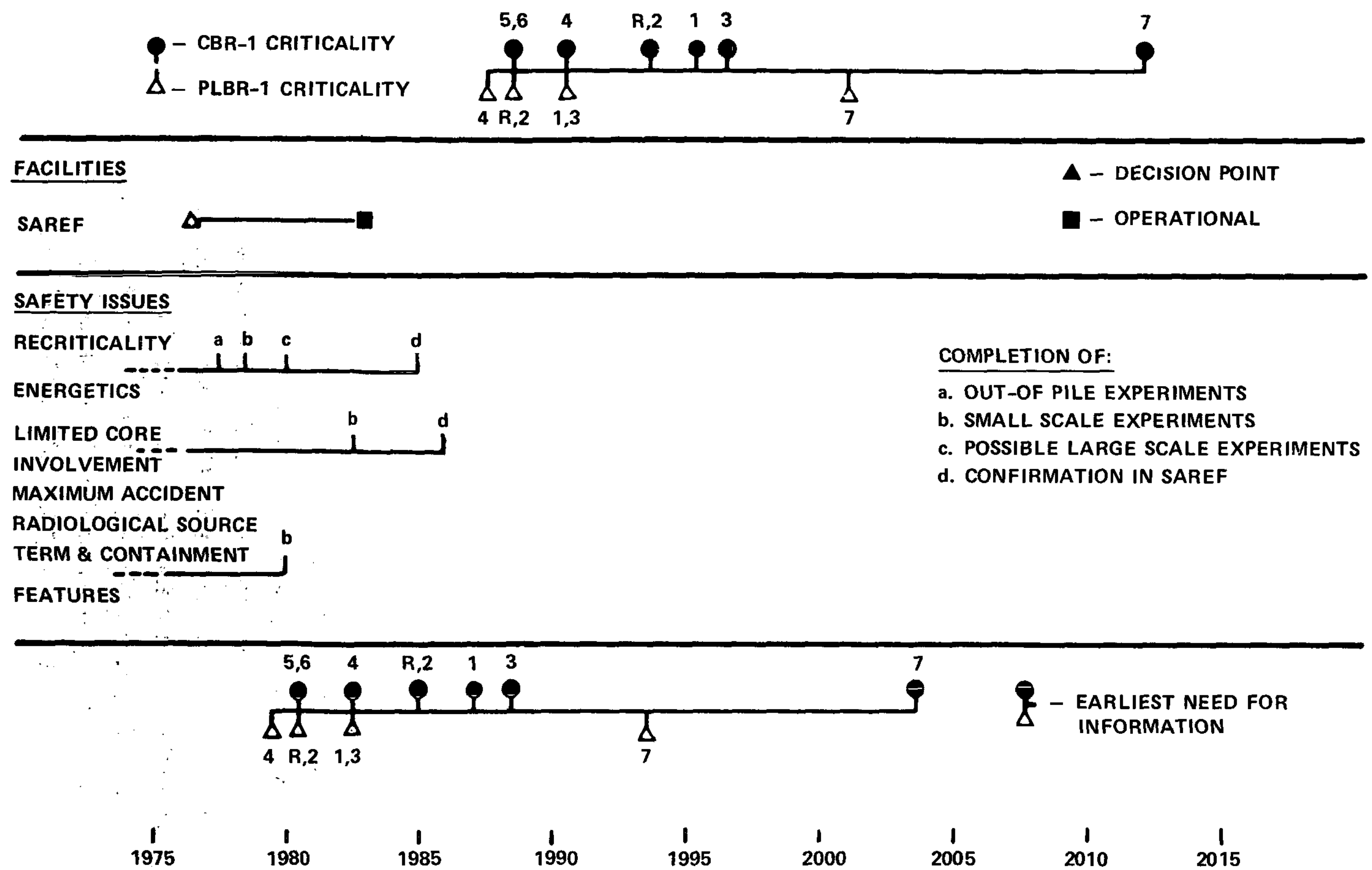
Figure I.4-1 presents information on milestones for achieving resolution of the three principal elements of the safety issue along with schedular information on the various alternative program plans reviewed in Section I.3. This Figure presumes the availability of SAREF on an early schedule. It should be noted that establishment of an adequate resolution of outstanding elements of the safety issue would be accelerated by, but does not necessarily depend on, the availability of SAREF. Since reactor safety information in large part relates to design considerations, it is believed that the safety issue should be resolved about one year before the reactor design is finalized. The alternative program analyses assume a three year design period and a seven year construction period prior to criticality so that the safety issue should be resolved eight years before the criticality dates indicated. It can be seen from examination of Figure I.4-1 that:

- All elements of the safety issue will receive final resolution in time for initial design of the first commercial breeder reactor for plans 1, 3 and 7;

- The reference plan and plan 2 would have available all the necessary safety data in time to factor it into the CBR-1 design;

- The accelerated plans 4, 5, and 6 would require that design be completed prior to complete confirmation of all elements of the safety issue.

As noted earlier this does not mean that prototype large breeders or commercial breeders cannot be built prior to these schedules. It merely means that additional conservatism must be built into the designs to compensate for lack of certainty on residual elements of the safety issue. Figure I.4-1 also indicates safety will not be an issue which will prevent wide-spread commercial deployment of LMFBRs where design starts in 1986 and thereafter.



Note: R refers to the Reference Program and numbers 1-7 refer to the alternative LMFBR Program Plans reviewed in Section I.3.

SAFETY PROGRAM COMPATIBILITY WITH ALTERNATIVE LMFBR PROGRAM PLAN MILESTONES

Figure I.4-1

I.4B WASTE MANAGEMENT PROGRAM COMPATIBILITY WITH ALTERNATIVE LMFBR PROGRAM PLAN MILESTONES

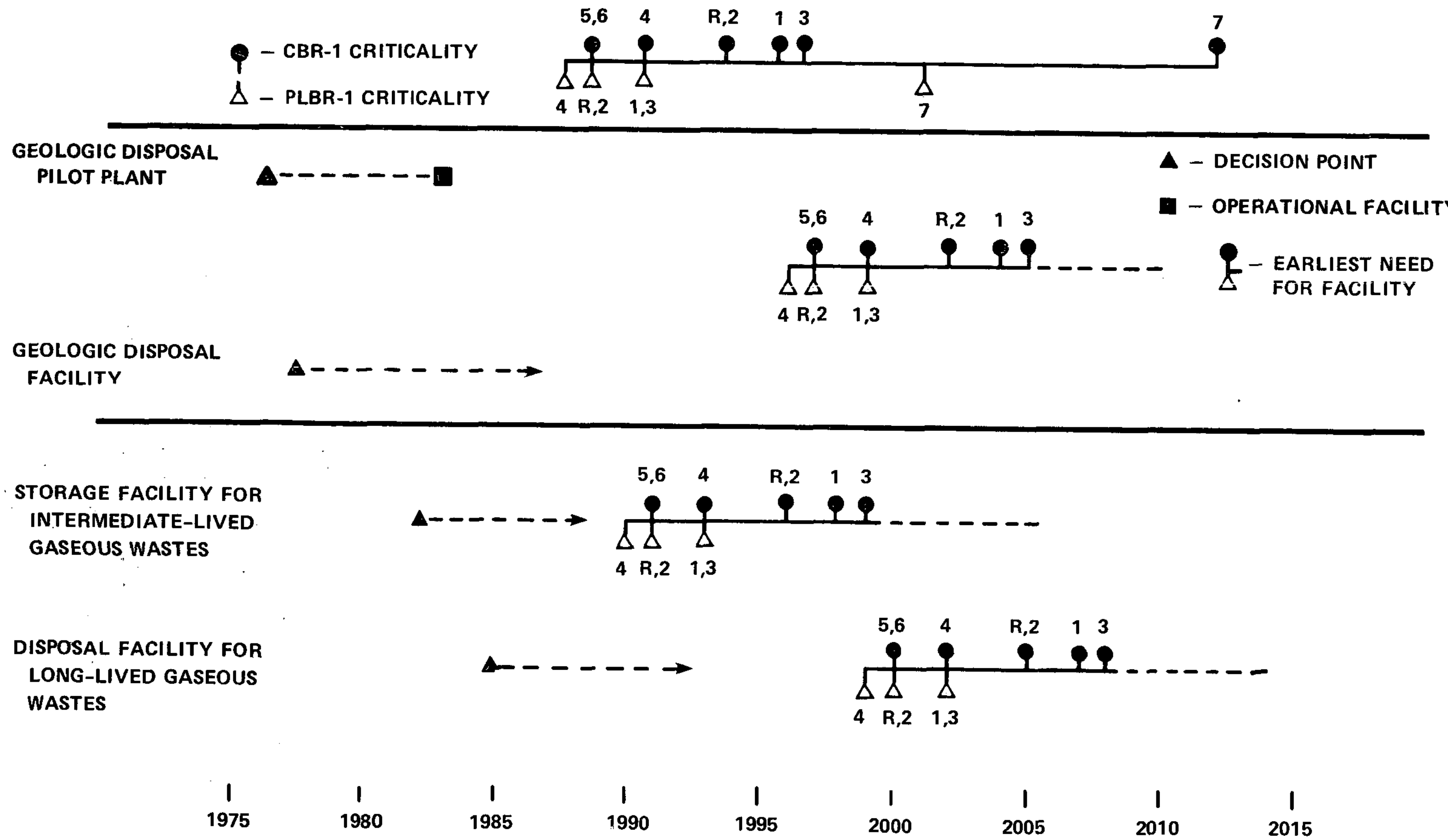
The opinion has been expressed in comments on the Draft and Proposed Final Environmental Statements (PFES) that the LMFBR Program should be delayed until a definitive method for permanent disposal of high-level and transuranium radioactive wastes has been fully established. The waste management program to accomplish this objective is described in Sections 4.6 and 7.3 of the PFES (incorporated as Section II) and Section III D of this Statement.

It has been pointed out that waste management and disposal is not an issue for the LMFBR fuel cycle alone but must be resolved for the LWR fuel cycle or any other nuclear fuel cycle whether or not the LMFBR is developed. However, in order to determine whether the waste management research, development and demonstration program will impose any constraints on the development schedule for the LMFBR, this program has been analyzed with reference to its interaction with the schedules of the reference plan and the seven alternative LMFBR Program plans reviewed in Section I.3.

It has been determined that the key element of the waste management program which has a bearing upon LMFBR schedules is the availability of a geologic disposal pilot plant. Ultimately, a permanent geologic disposal facility, a storage facility for intermediate-lived gaseous wastes, and a disposal facility for long-lived gaseous wastes will also be needed. Figure I.4-2 shows that a geologic disposal pilot plant for high-level and transuranium radioactive wastes is expected to be available by 1983, well in advance of requirements for the LMFBR Program.

Since disposal of high-level radioactive waste from LMFBR fuel reprocessing plants will not be required until about 12 years after start-up of an LMFBR, the earliest time that a waste disposal facility would be required for high-level wastes would be in 1999 for the prototype large breeder in plan 4 and the year 2000 for the first commercial breeder in plans 5 and 6.* Since it is expected that the geologic disposal pilot plant might be converted to a full-size facility if it proves successful, there does not appear to be any constraint on the LMFBR Program imposed by disposal requirements for high-level radioactive wastes. It should be noted from Figure I.4-2 that a decision to build a full-scale geologic disposal facility

*However, a geologic disposal facility may be needed as early as 1996 (plan 4) for disposal of significant amounts of transuranium wastes associated with the LMFBR fuel cycle. This consideration is reflected in Figure I.4-2. (See the PFES, Vol. II, pp. 4.6-1 and 4.5-24 for the definitions of high-level and transuranium--also called alpha or transuranic--wastes.)



Note: R refers to the Reference Program and numbers 1-7 refer to the alternative LMFBR Program Plans reviewed in Section I.3.

WASTE MANAGEMENT PROGRAM COMPATIBILITY WITH ALTERNATIVE LMFBR PROGRAM PLAN MILESTONES

Figure I.4-2

may be made in 1977. Although the operational date for such a facility has not been determined as yet, more than 20 years will elapse before the facility will be required for the LMFBR Program.

ERDA has recently restarted a program leading to the construction of a "pilot" disposal facility in bedded salt in southeast New Mexico. When this facility is ready to receive radioactive waste in the early eighties, treated plutonium waste from ERDA storage facilities will be the first material stored there. As the programs on solidification and packaging of high-level waste proceed to a point where sealed canisters of waste, ready for disposal, are available, the pilot facility may be used to further study the high-level waste disposal capabilities of bedded salt. The latter studies and other studies which will be made on the technical, environmental and economic aspects of disposal of high-level waste will form an important part of the overall program for isolation of commercial high-level waste and will provide required technical support for one or more additional facilities for such wastes.

The initial objective is to provide the facilities and capabilities to permanently dispose of ERDA transuranium waste. This objective is achievable with proven existing analytical capabilities and technology. Limited quantities of transuranium waste will be received and placed in the salt bed in a fully retrievable condition. Pilot plant operations will be continued until the observations and measurements made have demonstrated the safety and acceptability of the disposal mode, after which the pilot plant may be converted to a full capacity disposal operation wherein the waste will no longer be readily retrievable. Significant quantities of transuranium wastes from the LMFBR fuel cycle (i.e., too large to be temporarily stored at the generating sites) are not expected to be produced until about 1996.

At the present time, most of the long-lived gaseous fission products generated in reactor fuel are released at the spent fuel reprocessing plants. The principal radioactive isotopes involved are tritium, krypton-85, iodine-129, and carbon-14 (released as carbon dioxide). Both EPA and NRC are currently considering regulations for these gases which may prevent their emission at commercial plants in the mid 1980's. Work has been under way for some time at ERDA laboratories to develop ways to remove these radioactive gases from plant effluents and some of the developments have been applied to ERDA facilities. This development program is aimed at providing the technology needed to safely fix and store these wastes. Investigations of solidification techniques for each of these gases are now under development on a laboratory scale and pilot demonstrations are planned in 1978 for tritium and iodine, and 1979 for krypton. It is expected that only two facilities for management of these gaseous wastes will be required - one for storage of relatively short-lived wastes (tritium and krypton) and one for disposal of long-lived wastes (carbon-14 and iodine-129), although this latter waste may be placed in the geologic disposal facility.

It is expected that firm schedules for all these various waste management facilities and programs will be established during 1976. Additional details on these programs and potential facilities are given in Section III D. The intermediate-lived gaseous waste storage facility or an interim storage measure will not be needed until at least two-to-three years after initial startup of the PLBR-1 or CBR-1, whereas the long-lived gaseous waste disposal facility will not be required for ten years beyond that point. Decisions to construct these facilities may not be made until 1982 for the former and 1984 for the latter. As can be seen from Figure I.4-2, the earliest LMFBR requirement for the intermediate-lived gaseous waste storage facility would be 1990 for the prototype large breeder in the reference plan, and 1991 for the commercial breeder reactors in Plans 5 and 6. However, it is expected that interim storage at LMFBR power plants would be used to delay these dates to 1995 and 1996 respectively, since there will not be a significant volume of such wastes from the LMFBR fuel cycle until the mid-1990's.

I.4C SAFEGUARDS PROGRAM COMPATIBILITY WITH ALTERNATIVE LMFBR PROGRAM PLAN MILESTONES

A particular point raised by the Internal Review Board related to "minimization" measures, i.e., safeguards measures directed toward minimization (or, at least, reduction) of the adverse consequences of postulated successful adversary actions. Section III C.1 (subsection 7.4.8.1.2S) provides a discussion of a number of minimization (reduction) measures which are under consideration, and indicates the approach to be taken in assessing the degree of risk reduction which could be expected to result from implementation of these measures. It should be understood that the development of measures to minimize or reduce consequences of successful adversary acts, while an important activity, is only one element in the overall ERDA program for future safeguards. This program is discussed below in the particular context of compatibility with the alternative LMFBR Program plans.

Section II, 7.4.8.1.3 provides a general description of the ERDA program for future safeguards. Recent planning activities have resulted in an improved and more specific program description. This is given in Section III C.2 (subsection 7.4.8.1.3S). It is pointed out that the ERDA safeguards program relates to all nuclear fuel cycles, and that the safeguards requirements of the LMFBR are not unique. Nevertheless, it is recognized that improvements in the safeguards system will be needed in the future because of changes in the nature of the threat and the expected widespread commercial utilization of strategic special nuclear materials such as plutonium, and that LMFBR safeguards may differ in some details from the safeguards systems of conventional (LWR, HTGR) nuclear fuel cycles - possibly arising from the increased magnitude of plutonium present in the LMFBR fuel cycle. The following discussion relates to the development of the safeguards system specifically required for the LMFBR economy. It should be kept in mind that improvements in the existing safeguards systems for conventional nuclear fuel cycles are not dependent upon design information from the LMFBR Program and therefore are not dependent upon alternative LMFBR Program schedules.

As stated in III C.2, the ERDA safeguards program is expected to provide, by the early 1980s, information sufficient to permit an ERDA management decision on the safeguards-related acceptability of the LMFBR for future widespread commercial use, given the timely availability of design information pertinent to the future LMFBR fuel cycle. The information used in this decision process would result from four major safeguards program activities:

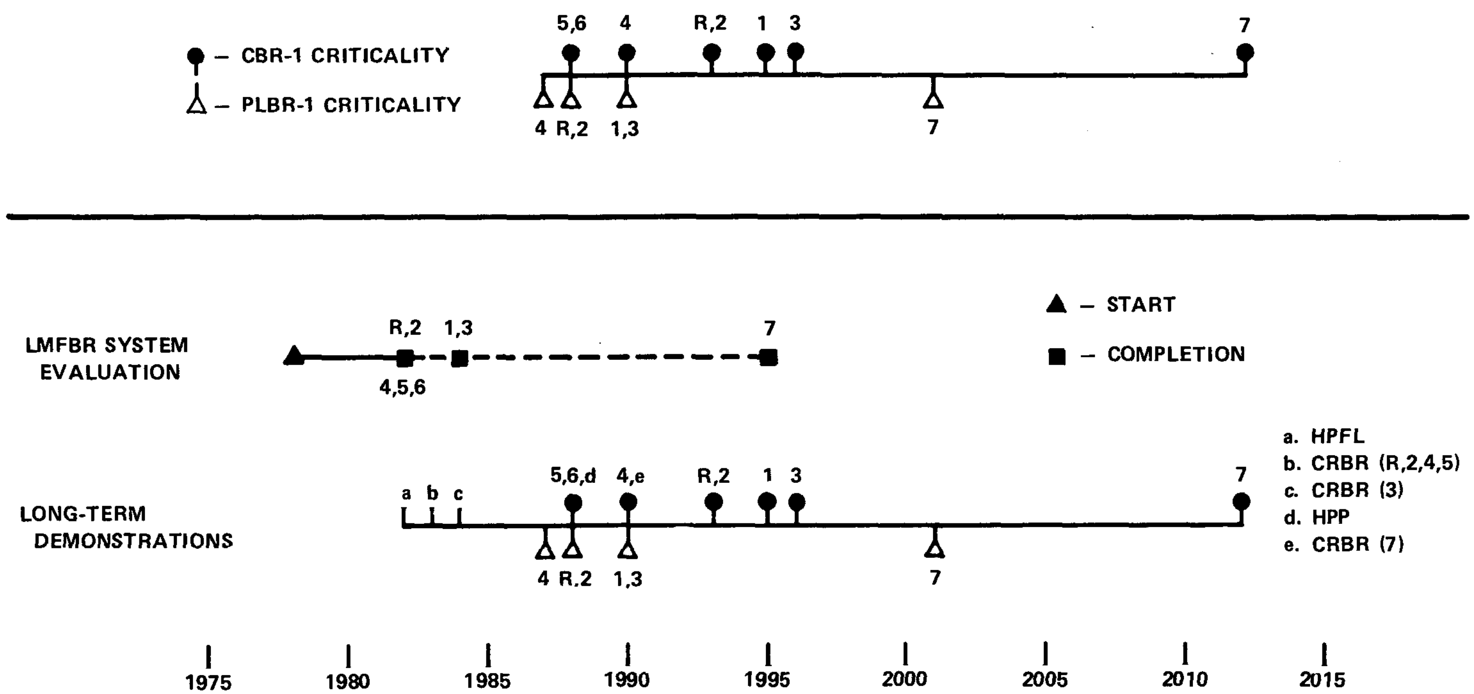
(a) Improvement of Threat Definition;
(b) Improvement of Safeguards System Design and Evaluation Capability;
(c) Improvement of Capability for Adversary Action Interruption and Consequence Reduction; and
(d) LMFBR Systems Evaluations.

The first three activities are essentially independent of LMFBR Program scheduling since they are needed for a nuclear power industry whether the LMFBR is developed or not. They will produce the methodology and technology necessary for the synthesis and effectiveness evaluation of safeguards systems for a future LMFBR industry. The synthesis and evaluation, carried out under activity (d), will lack credibility unless it utilizes realistic LMFBR facility design information, and other related LMFBR fuel cycle information. Thus, the timing for initiation and completion of activity (d) is influenced by LMFBR Program scheduling.

As indicated in Table III C-1 (Section III C.2, page III C-8), the necessary LMFBR design information is required for three kinds of facilities: reactor plants (CRBR and PLBR), fuel fabrication plants (HPFL), and reprocessing plants (HPP design study). It is assumed that other necessary information (e.g., design of transport systems) would become available concurrently with facility designs.

Of the facilities considered to influence the timing of safeguards program activity (d), only the reactor plants (CRBR and PLBR) appear in the alternative LMFBR Program plans, and PLBR is considered to be the essential element in obtaining a firm projection of future commercial LMFBR reactor plant design. Thus the timing for PLBR design (or CBR design in those cases which do not include PLBR) is a major LMFBR Program strategy factor which influences the timing of safeguards program activity (d), which is prerequisite to the ERDA management decision on future LMFBR safeguards-related acceptability.

As indicated in Table III C-1, it is judged that activity (d) could be completed by 1982, no later than one year after completion of PLBR design. This timing would apply for the reference LMFBR Program plan and for plans 2, 4, 5 and 6, (See Table I.3-1). For plans 1 and 3, activity (d) would be completed in 1984. For plan 7, it would be completed in 1995. These relationships are illustrated in Figure I.4-3. In addition to the completion of activity (d), which will permit a management decision on the widespread deployment of LMFBRs, demonstration in facilities placed in operation will provide continuing assurance that nothing has been overlooked.



Note: R refers to the Reference Program and numbers 1-7 refer to the alternative LMFBR Program Plans reviewed in Section I.3.

SAFEGUARDS PROGRAM COMPATIBILITY WITH ALTERNATIVE LMFBR PROGRAM PLAN MILESTONES

Figure I.4-3

The times at which various facilities are expected to come into initial operation or go critical are also presented in Figure I.4-3.

Since widespread commercial deployment of LMFBRs is not expected before the late 1990s, it is apparent that safeguards will not be a constraint on their deployment under any of the alternative plans reviewed in Section I.3.

I.4D TRANSURANIC* HEALTH EFFECTS PROGRAM COMPATIBILITY WITH ALTERNATIVE LMFBR PROGRAM PLAN MILESTONES

Despite the fact that plutonium has been recognized as a hazardous radioactive substance ever since it was first produced and its health effects have been studied since that time, plutonium toxicity remains one of the most controversial issues in the nuclear power program. The subject of plutonium toxicity is discussed in Volume II, Section 4.7 and Appendix II.G of the PFES and the transuranic health effects program is described in Section III G.

Transuranic health effects research is not easily categorized in terms of schedules and definitive goals. The subject involves painstaking research on the toxic effects of a material for which the effects may not become manifest in humans for decades after exposure. In the absence of any observed health effects to date which can be related to plutonium exposure in humans, a variety of extensive studies are being conducted in order to define both effects and mechanisms resulting from the internal deposition of alpha-emitting radionuclides. This is a continuing effort, and, since information and concerns are not constant, it is not realistic to project that the plutonium toxicity issue will be definitively resolved at some fixed point in time.

Nevertheless, there is a large program underway (see Section III G) to help resolve the transuranic health effects issue and this program has goals with approximate time schedules associated with each. Figure I.4-4 shows the major research areas in which effort is being focused and the time period in which results are expected. Results of research and development completed, underway or to be initiated in the near future will better define dose-response relationships and lead to improved radiation protection criteria regarding exposures to transuranics within the next 10-20 years.

*Transuranic - all elements including plutonium with atomic numbers greater than 92.

HUMAN STUDIES	GOAL
Transuranium Registry	Sufficient data for conclusions in 10-20 years
ANIMAL STUDIES	
"Hot particle" investigation	Conclusion in 5-10 years
Effects of long-term, low level exposures to transuranics	Studies completed in 10-20 years
Recovery/treatment processes	Initial results in 3 years

TRANSURANIC HEALTH EFFECTS PROGRAM GOALS

Figure I.4-4

The statement provided on May 27, 1975 by ERDA staff for the Public Hearing on the LMFBR Program Proposed Final Environmental Statement contained a discussion on plutonium health effects which is germane to this discussion:

> "One of the most controversial items under this generic issue is that of plutonium toxicity. The comment letters received from the public indicate that the toxicity of plutonium has been impressed upon some members of the general population as an unprecedented peril of such magnitude that the generation and use of plutonium should be avoided. This is a distorted picture of what is known about plutonium in the environment.
>
> "It is the view of the ERDA staff that whether plutonium is more or less hazardous than other natural and industrial materials is beside the point and obfuscates the real issue, which is the extent of the hazard to which the population is exposed from a particular material. The toxicity of plutonium had been recognized long before the outset of the LMFBR Program and extraordinary measures have been taken in the nuclear power reactor program to isolate plutonium from the environment. It is believed that the data presented in Section 4.7 and Appendix II.G of the Proposed Final Statement amply demonstrate that the hazard is very small indeed.

"More specifically, concern regarding toxicity of plutonium and transuranic elements produced in the LMFBR fuel cycle appears to be based on the following points:

a. Large quantities would be produced.
b. Once released many of these elements will persist in the environment for thousands of years.
c. Although there is no direct knowledge of effects in man, the toxicity of these materials is well demonstrated in experimental animals.
d. Such effects as might conceivably occur may be indistinguishable from the normal ills of mankind.

"The concern about plutonium has crystallized in the presentation of the 'hot particle' issue, advanced principally by the Natural Resources Defense Council. This issue is that the health risks as presented in the PFES might be underestimated because the possibility of carcinogenic risk to the respiratory tissues from small, discrete, highly radioactive alpha-emitting particles (hot particles) deposited in the lung might be very much greater than that obtained using commonly accepted methodology.

"This issue is fully presented and discussed in the PFES. Subsequent to the issuance of the PFES, other organizations have published or are about to publish independent analyses of the hot particle hypothesis. The Los Alamos Scientific Laboratory, the National Council on Radiation Protection and Measurements, the National Radiation Protection Board of the United Kingdom, and the Medical Research Council of the United Kingdom have independently analyzed the 'hot particle' hypothesis, and in each case have found it neither supportable nor valid. The National Academy of Sciences is also examining this hypothesis at the request of both ERDA and EPA.

"In view of the evidence available and of the preponderance of scientific opinion, the ERDA staff position is that it would not be prudent to make decisions based upon such a poorly supported hypothesis and that the risk estimates used in the PFES reflect the best information and scientific judgment available."

It should be noted that the transuranic health effects program is directed solely towards defining the health effects of transuranic elements and does not address the release rates (or the source term) for the transuranic elements. Keeping the release rates to acceptably low levels is a prime function of other portions of the LMFBR Program such as safety, waste management and safeguards, which have been discussed in this Section and Section III, as well as in the PFES.

REFERENCES FOR SECTION I

1. LMFBR Program Plan (WASH-1101 through -1110), August 1968.

2. LMFBR Program Plan (WASH-1101 through -1110, 2nd edition), December 1973.

3. Findings Supporting Determination in Regard to LMFBR Base Program Pending Preparation of Section 102(2)(C) NEPA Impact Statement, March 25, 1974.

4. Environmental statement on the Fast Flux Text Facility, Richland, Washington, WASH - 1510, May 1972.

SECTION II

PROPOSED FINAL ENVIRONMENTAL STATEMENT

FOR THE

LIQUID METAL FAST BREEDER

REACTOR PROGRAM

DECEMBER 1974

WASH-1535

II. DESCRIPTION OF THE CONTENTS OF THE PROPOSED FINAL ENVIRONMENTAL STATEMENT

This section is comprised of the seven-volume report, "Proposed Final Environmental Statement for the Liquid Metal Fast Breeder Reactor Program," WASH-1535 (December 1974), which is incorporated as an integral part of the Final Environmental Statement (FES) to the extent consistent with the Administrator's Findings of June 30, 1975. It should be noted that any policy determinations found in the Proposed Final Environmental Statement (PFES) should be considered as modified by ERDA's subsequent policy determinations on the basis of the FES. The PFES is distributed under separate cover to those recipients of the Final Environmental Statement who have not previously received the report during the review and comment process. To assist the reader, a short description of the contents of WASH-1535 is provided in Figure II-1.

Volume I	Section 1	Summary
	Section 2	Background
	Section 3	LMFBR Program
Volume II	Section 4	Environmental Impact of the LMFBR Fuel Cycle
	Section 5	Economic, Social and Other Impacts
Volume III	Section 6	Alternative Technology Options
Volume IV	Section 7	Mitigation of Adverse Environmental Impacts
	Section 8	Unavoidable Adverse Environmental Impacts
	Section 9	Short Term Benefits and Long Term Losses
	Section 10	Irreversible and Irretrievable Commitments of Resources
	Section 11	Cost-Benefit Analysis
Volume V	Appendix	Comment Letters 1-25 and Responses
Volume VI	Appendix	Comment Letters 26-38 and Responses
Volume VII	Appendix	Comment Letters 39-66 and Responses

CONTENTS OF PROPOSED FINAL ENVIRONMENTAL STATEMENT

Figure II-1

The Proposed Final Environmental Statement was prepared in seven volumes, each containing one or more Sections, the titles of which are listed in Figure II-1. A Table of Contents is contained in each volume and a summary is provided in front of each Section. The outline and contents of the Statement generally follow the subject coverage required by the National Environmental Policy Act (NEPA) of 1969.

VOLUME I contains a summary of the entire Environmental Statement and background information on the U.S. energy economy, the LMFBR Program and the relationship between the two. It includes discussion of the past, current and projected uses of energy and its importance to society, and describes the role of electricity, including that produced by nuclear reactors, in helping to meet the Nation's energy requirements. This volume also summarizes the origins and history of the LMFBR Program and provides a brief discussion of the several experimental and special purpose fast reactors that have been built in the United States since the late 1940's. Volume I also reviews the fast reactor programs in other industrialized nations. A discussion of the current U.S. LMFBR Program is offered which highlights the important program planning mechanisms, the key reactor plants now under design and construction, and the various supporting studies on LMFBR costs, technology, environmental impacts, and program planning. This volume lays the background for examination of the environmental characteristics of the LMFBR.

VOLUME II describes the direct environmental impact of each element of the LMFBR fuel cycle. It examines the power reactors, fuel fabrication plants and fuel reprocessing plants that make up the LMFBR fuel cycle and discusses for each the siting considerations, plant characteristics, effects on the environment from construction and normal operation, and environmental monitoring programs that together entail a complete environmental evaluation. Volume II also includes an evaluation of the potential environmental impacts of various types of accidents in the facilities comprising the LMFBR fuel cycle. In addition, this volume examines the transportation of radioactive materials between these facilities and the management of radioactive wastes produced in LMFBR activities, and analyzes in detail the properties of plutonium and its behavior in the environment, and the resulting health effects. Extensive supporting data are provided in the appendices to Volume II. The volume concludes with an examination of the related sociopolitical impacts of the LMFBR.

VOLUME III examines individually the various alternative technologies, nuclear as well as nonnuclear, that might be utilized in conjunction with or instead of the LMFBR to satisfy the Nation's future electric power requirements. The options considered include the further implementation of various types of nuclear power reactors such as the already existing Light Water Reactor and High Temperature Gas-Cooled Reactor, as well as the development of alternative breeder reactors such as the Gas-Cooled Fast Reactor, Light Water Breeder Reactor and Molten Salt Breeder

Reactor. The development of another potential nuclear energy system, controlled thermonuclear fusion, is also addressed. The possibilities of increased emphasis on the use of conventional fossil fuels, namely coal, oil and natural gas, and the development of unconventional fossil fuels such as oil shale and domestic tar sands are discussed next, followed by consideration of the further development of additional nonnuclear energy sources such as hydroelectric power systems, geothermal energy, solar energy, and other potential sources of power. Each option is examined as to the extent of its energy resource base, the research and development program that would be required (if any) to bring the option into commercial use, the environmental implications of its utilization and the costs and benefits associated with its use, in order to assess its capability for satisfying projected energy requirements. This volume also discusses the use of improved energy conversion and storage devices such as gas turbines, fuel cells and magnetohydrodynamics, and concludes with an examination of the various elements of a potential national effort in energy conservation to assess their capabilities for reducing projected energy demands and thereby replacing partially or entirely the need for additional power sources such as the LMFBR.

VOLUME IV provides a broad overview of the many implications of LMFBR Program implementation, up to and encompassing a fully developed LMFBR power plant economy, including the secondary impacts, the unavoidable adverse environmental impacts, cumulative environmental impacts, and cost-benefit analyses, and also discusses alternative energy strategies. Under the heading of secondary impacts, it examines the national implications of the availability of electricity from LMFBRs, and the specific economic impacts of the LMFBR Program. This volume also discusses the currently feasible alternatives and potential future alternatives for mitigating adverse environmental impacts of the LMFBR fuel cycle, and in this context analyzes the problems of safeguarding special nuclear material from potential diversion to unauthorized purposes. Also covered in Volume IV are the cumulative environmental effects of LMFBR operation to the Year 2020, the decommissioning of LMFBRs and fuel cycle facilities upon the completion of their useful life, the irreversible and irretrievable commitments of resources that will accompany implementation of an LMFBR economy, and an analysis of the costs and benefits of implementing the LMFBR Program.

VOLUMES V - VII contain copies of all formal comments received on the Draft Statement and copies of the AEC's replies. Where appropriate, these comments have been identified and discussed in the text, and are further identified by footnotes indicating the letter and page number in which the comment appears.

For the convenience of the reader, the major topics contained in the PFES are summarized in a Table of Contents beginning on the following page.

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8. UNAVOIDABLE ADVERSE ENVIRONMENTAL IMPACTS OF THE LMFBR

γ

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CONTENTS OF PFES (Continued)

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CONTENTS OF PFES (Continued)

SECTION III

SUPPLEMENTAL MATERIAL

INTRODUCTION

Section III includes revisions of material presented in Section II (Proposed Final Environmental Statement (PFES), WASH-1535) as well as supplemental material requested on a number of issues as a result of review of the written comments received, the testimony presented at the Public Hearing held on May 27-28, 1975, the Report to the Administrator by the Internal Review Board (see Section IV B) and the Findings of the Administrator (see Section IV A). This Section should be consulted whenever Section II is used to determine whether revised or supplemental material has been provided.

Section III A includes substantive revisions to the text of the PFES as appropriate to correct errors or update data which has changed significantly enough to qualify conclusions reached in the PFES. It does not contain corrections of typographic errors which are self-evident or updating of that data which would not significantly bear upon the conclusions reached.

Section III B provides supplementary information on the LMFBR safety program in order to more completely define the steps being taken to assure the safety of the LMFBR.

Section III C supplements the safeguards information provided in the PFES in response to requests for a more complete definition of the program being pursued to assure that a widespread LMFBR electricity generating economy will be adequately protected against sabotage, diversion of nuclear materials and other antisocial acts.

Section III D: a) discusses the present situation with regard to migration of radioactivity from commercial low-level waste burial grounds; b) discusses an issue not fully treated in the PFES, namely doses due to C^{14} releases in the LMFBR fuel cycle; and c) updates the discussion of the waste management program presented in the PFES.

Section III E provides additional information or measures being taken to develop data with which to better define the Nation's uranium resources.

Section III F provides additional cost-benefit analyses in two areas: a) alternative nuclear and non-nuclear energy strategies and b) updated cost-benefit analyses utilizing more current information on uranium and separative work prices.

Section III G describes the ERDA program on transuranium health effects in greater detail than was provided in the PFES.

Section III H describes the current programs for developing solar electric and controlled thermonuclear fusion energy systems. These systems have been identified in ERDA-48, "A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future" as "inexhaustible" alternative energy options for the long-term along with the breeder reactor. The discussion presents the ERDA plan for development of these systems and the milestones for achievement of the goals as presented in ERDA-48.

SECTION III A

REVISIONS TO TEXT OF

PROPOSED FINAL ENVIRONMENTAL STATEMENT

Section 1 - SUMMARY - Vol. 1

page 1.3-2 - line 12 - change "The LMFBR power plant site would occupy a minimum area..." to read: "The LMFBR power plant site would occupy an area...".

This change avoids the implication that 10 CFR 100 sets forth the acreage required for a power plant site; it does not.

Section 2 - BACKGROUND - Vol. I

page 2.1-7, paragraph 2, line 8 - "Na ion" should read "Nation"

Section 3.5.2S - THE CLINCH RIVER BREEDER REACTOR - Vol. I

CRBRP PROJECT MANAGEMENT ARRANGEMENTS

Since the issuance of the PFES, several important changes in the Clinch River Breeder Reactor Plant (CRBRP) Project management arrangements have been proposed and are currently in the process of being approved and implemented. These changes recognize that the continuation of the Federal Government's financial commitment to the CRBRP Project, with a fixed financial commitment from the electric utilities, required alignment of direct management authority with the much larger financial responsibilities of the Government, and integration and streamlining of the management mechanism for executing the Project under single direction. The Project Management Corporation (PMC), while no longer responsible for the direct management of the Project, will administer the utilities' interests in the Project. Legislation is pending before Congress which would give the Joint Committee on Atomic Energy the authority to approve the proposed changes in CRBRP Project management arrangements.

In cooperation with the several principal participants in the project, a management structure is being established as a single, integrated organization, designated as the Clinch River Breeder Reactor Plant Project Office, to be staffed by both Government and industry personnel. The Director, CRBRP Project Office, an ERDA official serving under the management direction of the Director, Division of Reactor Research and Development (RRD), will supervise the entire CRBRP Project Office staff and manage the Project. Functions and responsibilities for the Project may be delegated to the Director, CRBRP Project Office, or others, by the Director, RRD.

The General Manager, PMC, will be Assistant Director in the office of the Director, CRBRP Project Office. He will play an active and leading role in overall project planning, engineering and execution, though he will not be authorized to directly control Project activity. The PMC will have a small office - 3 to 5 people - for the conduct of business that is appropriately that of PMC, such as the hiring of PMC personnel for the Project Office staff, providing financial accountability for utility industry funding furnished to the Project through the Breeder Reactor Corporation (BRC), providing liaison between the participating utilities and the Project Office, and keeping the utility industry informed of Project activities through the BRC. This PMC office will be co-located with the Project Office.

The fundamental premise for operation of the Project Office is that the Federal Government and the utility industry will organize, staff, and conduct business in a way that provides for a single, integrated management that recognizes and accepts control of the Project by the Government while affording wide opportunity for the participating utilities to have a voice and exercise a strong, active management role through the PMC organization. Employees of the Energy Research and Development Administration will head the offices that generate policy, give final approval to requirements, commit Government resources, and give final acceptance and approval of contractor action. ERDA employees will also head the organizational elements responsible for fiscal and financial management as well as cost and schedule control.

Staffing of the CRBRP Project Office will include both ERDA and PMC employees. PMC employees on the Project Office staff will be hired and paid by PMC but will be responsible to the Director, CRBRP Project Office. Persons employed through PMC will be given responsible, meaningful supervisory jobs in order that the utility industry can contribute from its wide range of skills and experience while at the same time developing these career utility employees through participation in the breeder reactor technology programs, and in plant design, construction and operation.

Section 4.1 - INTRODUCTION - Vol. II

page 4.1-9, Table 4.1-2 - "27,700" should be "22,700".

Section 4.2 - LMFBR POWER PLANTS - Vol. II

page 4.2-3 - delete the last sentence of the second paragraph in section 4.2.2.1. This deletion avoids the implication of presumption with respect to future actions by the Nuclear Regulatory Commission, which was not intended.

page 4.2-60, second paragraph, line 7 - delete "and free oxygen". This is an error.

page 4.2-64, line 4 - change the sentence beginning: "Thus, of utmost importance..." to read: "Thus, in the choice of the cooling method for an LMFBR plant, it is of considerable importance to pay attention to the horizontal and vertical extent of the thermal plume".

Use of the word "utmost" involved the unintended implication that the configuration of the thermal plume is virtually the only consideration in the choice of cooling method. Other important factors are also involved.

page 4.2-102, paragraph beginning at bottom of page, line 8 - change "... Reports for Nuclear Power Plants.[126]" to read: "...Reports for Nuclear Power Plants, for guidance in implementing the regulations.[126]"

page 4.2-122, fourth paragraph, first sentence - change to read:

"The reactor shutdown system and containment isolation system will employ..."

Insertion of the word "will" emphasizes that this is a requirement and not an accomplished fact.

page 4.2-153, first paragraph, last sentence - change to read:

"The most prototypic experiments which have been performed to date in the TREAT reactor have produced conversion efficiencies of no more than 0.2%."

Add the sentence:

"The interpretation of TREAT experiments to LMFBR accident sequences is discussed in more detail in ANS-RAS-74-19 (particularly Chapter 4)."

The use of the phrase "under prototypic LMFBR accident conditions" was inappropriate.

page 4.2-153, second paragraph, first sentence - change to read:

"The experimental and analytical evidence[171-177] to date..."

page 4.2-140, last paragraph, first sentence - change to read:

"Analyses[144] of large pipe ruptures for current LMFBR designs..."

Insertion of the words "for current LMFBR designs" is intended to emphasize the fact that such analyses are dependent on specific plant design features and should be associated with specific plants.

page 4.2-141, first paragraph, first sentence - change to read:

"Since the analysis of pipe ruptures is dependent on specific design features, potential pipe ruptures will continue to be assessed for each LMFBR."

page 4.2-146, fourth paragraph - insert the following sentence just before the last sentence of the paragraph:

"While the disassembly energy potential depends on the specific reactor design and cannot be defined within narrow bands, it is expected that R&D efforts will, in the not very distant future, provide a basis for the conclusion that core disruptive accidents resulting in the generation of significant amounts of mechanical energy are physically unrealizable."

page 4.2-148, first paragraph, last sentence - insert the word "tentative" before "conclusion" and add the following sentence:

"Further study of repeated and continued criticality is planned."

page 4.2-159 - insert the following sentence after the first sentence under section 4.2.7.8.3:

"Detailed assessments for reactors larger than FFTF are not yet available, and more analysis is needed to understand the effects of possible larger sodium voiding and clad/fuel motion reactivity effects on the energetics of an HCDA."

delete the words: "As noted" appearing at the beginning of the second sentence.

page 4.2-214 - paragraph beginning "The tornado design bases...", change:

"300 mph"	to	"290 mph"
"60 mph"	to	"70 mph"
"3 psi in 3 seconds"	to	"2 psi per second"

These changes conform the paragraph to the recommendations of Regulatory Guide 1.76 - Design Basis Tornado for Nuclear Power Plants.

Section 4.3 - FUEL FABRICATION PLANTS - VOL. II

page 4.3-76, first paragraph under 4.3.8.1, line 6 - delete the sentence beginning "AEC Division of Construction..." and replace with:

"As provided in 10 CFR Part 70, Section 70.23(b), 'the Commission will approve construction of the principal structures, systems and components of a plutonium processing and fuel fabrication plant on the basis of information filed pursuant to § 70.22(f) when the Commission has determined that the design bases of the principal structures, systems and components, and the quality assurance program provide reasonable assurance of protection against natural phenomena and the consequences of potential accidents'."

page 4.3-108 - Reference 70 is deleted.

Section 4.4 - FUEL REPROCESSING PLANTS - VOL. II

page 4.4-42, Table 4.4-4 - The concentrations for cm-242 should be 7.69E-12 and 1.82E-11, not 7.69E-11 and 1.82E-10.

Section 4.5 - TRANSPORTATION OF RADIOACTIVE MATERIALS - Vol. II

page 4.5-34, paragraph 4, line 4 - "8.05 year" should read "8.05 day".

page 4.5-41, last paragraph - place an asterisk after "special-form" and add the following footnote:

"*The use of special-form inner packages for PuO_2 is assumed here, although not currently required."

Section 4.7 - PLUTONIUM TOXICITY - Vol. II

page 4.7-10 - Since the PFES was prepared, several papers[1,2,3,4] have been presented or published which are relevant to the estimates of risk for exposure to plutonium discussed in Sections 4.7.6 and II G-5.

Bair and Thomas[1] present estimates of the risk of lung cancer in the rat based on data from numerous observations on experimental animals exposed to various compounds of alpha-emitting transuranic radiolnuclides, including very recent observations of Sanders[2] on rats receiving lung doses down to approximately 1 rad from $^{238}PuO_2$ and $^{239}PuO_2$. They conclude that the lung cancer risk for rats from inhaled alpha-emitting radionuclides is 8×10^{-4} per rad (16×10^{-5} per rem) for insoluble compounds. These values are not very different from those presented in Table 4.7-4 of the PFES.

Risk estimates based on human experience have been published recently by Bair and Thomas[1], Mays[3], and the Medical Research Council of the United Kindgom[4]. These have not been reviewed by the BEIR committee of the National Academy of Science. The risk estimates for lung and bone are very similar to those used in the PFES; those for liver are up to an order of magnitude higher. The authors point out that their liver risk estimates are very uncertain because of possible effects associated with the chemical carcinogenicity of thorotrast[3,4], and differences in aggregation between thorotrast and plutonium in the liver[4].

Considering the uncertainties involved, none of these recent risk estimates appear to substantively affect the description of potential hazards of plutonium presented in the PFES.

1. Bair, W. J. and Thomas, J.M., "Prediction of the Health Effects of Inhaled Transuranium Elements from Experimental Animal Data," Presented at the International Atomic Energy Agency Symposium on Transuranium Nuclides in the Environment, San Francisco, California, November 17-21, 1975.

2. Sanders, C.L., "Inhalation Carcinogenesis of High-Fired $^{238}PuO_2$ and $^{239}PuO_2$ in Rats," submitted for publication.

3. Medical Research Council, "The Toxicity of Plutonium," Her Majesty's Stationery Office, London, 1975.

4. Mays, C.W., "Estimated Risk from ^{239}Pu to Human Bone, Liver, and Lung," Presented at the International Atomic Energy Agency Symposium on the Biological Effects of Low-Level Radiation, Chicago, Illinois, November 3-7, 1975.

page 4.7-11, Table 4.7-2 - Revised Table is provided. Revisions pertain to column "Reference to Appendix Tables."

page 4.7-12, Table 4.7-3 - Revised Table is provided. Revisions pertain to column "Fallout Plutonium from Weapon Tests" and to footnote c.

page 4.7-15, Table 4.7-4 - Change footnote a to read "Condensed from Tables II.G-22 and II.G-23, Appendix II.G.5.3.

Appendix II.G - PLUTONIUM TOXICITY - Vol. II

page II.G-7, Table II.G-2 - under "Type of Accident" column, delete "Class 9" and subsitute "Hypothetical".

page II.G-46, Table II.G-15 - Revised Table is provided. Revisions pertain to column "Dose Equivalent to Current Generation from Fallout Pu".

Section 6A.1.1 - LIGHT WATER REACTORS - Vol. III

page 6A.1-3, Table 6A.1-2 - Estimated U.S. Uranium Resources, has been superseded by revised estimates. See Table III E-I in Section III E of this volume.

Table 4.7-2S

SUMMARY OF PRINCIPAL MODEL ASSUMPTIONS AND PREDICTIONS

	Reference to Appendix Tables	For Generating Capacity of 1000 MWe-year	For Year 2020 Generating Capacity of 2,200,000 MWe-year
Transuranics Released to Air (Ci)	II.G-1	0.36×10^{-3}	8×10^{-1}
Initial Transuranic Concentration in Soil (Ci/g - all in top 20 cm)	II.G-8	1×10^{-22}	2×10^{-19}
Initial Transuranic Concentration in Food (Ci/g)	II.G-8	1×10^{-23}	2×10^{-20}
Transuranics Ingested by U.S. Population (Ci)	II.G-8	4×10^{-6}	9×10^{-3}
Absorbed from G.I. Tract (Ci)	II.G-8	4×10^{-10}	9×10^{-7}
Transuranics Inhaled by U.S. Population			
Directly Inhaled (Ci)	II.G-5	1.4×10^{-9}	3×10^{-6}
Inhaled after resuspension			
During first 2 years (Ci)	II.G-5	0.8×10^{-9}	2×10^{-6}
After first 2 years (Ci)	II.G-5	2.5×10^{-9}	6×10^{-6}
Total Inhaled (Ci)	II.G-5	5×10^{-9}	1×10^{-5}
Radiation Dose to U.S. Population from Transuranics			
To lung (man-rem)	II.G-10	4	9×10^{3}
To bone (man-rem)	II.G-11	26	6×10^{4}
To liver (man-rem)	II.G-12	11	2×10^{4}
To thoracic lymph nodes (man-rem)	II.G-13	200	4×10^{5}
To gonads (man-rem)	II.G-14	0.4	9×10^{2}

Table 4.7-3S

COMPARISON OF ESTIMATED EXPOSURE FROM LMFBR TRANSURANIC ELEMENT RELEASE WITH EXPOSURES FROM OTHER SOURCES

	Units	Transuranic Release from LMFBRs in Year 2020[a]	Plutonium-Exposed Workers[b]	Fallout Plutonium from Weapons Tests[c]	Naturally Occurring α-Emitters[d]	Total Natural Radiation[d]
Total Released to Air	Ci	0.8		16,000		
Concentration in Soil	10^{-18} Ci/g	0.2		4,000		
Concentration in Plant-Derived Food	10^{-20} Ci/g	2.0		400		
Total Inhaled by U.S. Population	10^{-5} Ci	1.				
Total Deposited in U.S. Population	10^{-5} Ci		0.5	60	10,000	
Dose Equivalent to U.S. Population[e]						
Lung	10^4 man-rem	0.9		320	80,000[f]	
Bone	10^4 man-rem	6.		680	50,000[f]	200,000[f]
Liver	10^4 man-rem	2.		340		
Lymph nodes	10^4 man-rem	40.		19,000		
Gonads	10^4 man-rem	0.09			5,000	60,000

[a]Estimated release for an assumed generating capacity of 2,200,000 MWe-year. Numbers taken from Table 4.7-2.

[b]Numbers derived in Appendix II.G.5.1.

[c]Numbers derived in Appendix II.G.3 and II.G.5.1.

[d]Numbers derived in Appendix II.G.5.2.

[e]Dose equivalent from LMFBR release is a 70-year dose commitment (30 years for gonads) to all persons exposed for all time. Dose equivalent from fallout plutonium is a dose commitment to the Year 2000 for all persons exposed from 1954 to 1972. Dose equivalent from natural radiation is calculated for 70-year exposure of 2 x 10^8 people (30-year exposure for gonads).

[f]Dose to bone-lining cells.

Table II.G-15S

ESTIMATED MAN-REM EXPOSURE FROM FALLOUT PLUTONIUM AND FROM LMFBR TRANSURANIC RELEASES

Organ	Dose Equivalent To Current Generation from Fallout Pu[a] (man-rem)	Dose Equivalent to all Subsequent Generations from LMFBR Transuranic Releases (man-rem)	
		For Generating Capacity of 1000 MWe-Year[b]	For Year 2020 Generating Capacity of 2,200,000 MWe-year
Lung	3.2×10^{6}	4	0.9×10^{4}
Bone	6.8×10^{6}	17	$4. \times 10^{4}$
Liver	3.4×10^{6}	7	$2. \times 10^{4}$
Lymph nodes	190×10^{6}	200	40×10^{4}
Gonads	----	0.23	0.05×10^{4}

[a]Estimate of Bennett, based on New York City air concentrations.[60]

[b]Derived in Tables II.G-10 to II.G-14.

page 6A.1-9, Section 6A.1.1.2.2 - The sentence beginning: "As depicted in Figure 6A.1-5[6]..." (8 lines from top of page) should be deleted and replaced by the following two sentences:

"The U.S. and foreign uranium supply-demand situation through 1985 is depicted in Figure 6A.1-5[6]. Beyond 1985, the foreign uranium supply-demand[7,8] situation is expected to be much like that projected for the U.S. (see following section and Section 6A.1.1.8)."

page 6A.1-9 - The first sentence in Section 6A.1.1.2.3 should be deleted and replaced by the following sentence:

"Uranium production in the U.S. is currently at the rate of 12,000 tons of U_3O_8 per year (1974) but will need to increase rapidly -- in the range of 30,000 to 36,000 tons/year by 1980 and 84,000 to 125,000 tons/year by 1990 -- to keep up with estimated demand."

page 6A.1-26 - Delete the footnote and replace with the following:

"*The Light Water Reactor industry contemplates the use of PuO_2 in lieu of enriched UO_2 in some replacement fuel cores. It should be noted, however, that the Nuclear Regulatory Commission has not yet made a decision on whether to permit commerical recycling of plutonium in light water reactors."

page 6A.1-46, Table 6A.1-5 - change (Ci/liter) to read (pCi/liter) in headings for third and fifth columns in Table.

page 6A.1-47 - The last sentence of the middle paragraph, beginning: "The volume of ventilating air,..." should be deleted and replaced by the following sentences:

"The volume of ventilating air discharged from underground uranium mines is large in comparison with other mines, because of the need to dilute radon gas emanating from the uranium ore. While the discharged mine air may contain significant total quantities of rock dust and radioactive gases, the large quantities of diluent air carrying these materials - combined with natural dispersion in the atmosphere - result in concentration levels at the site boundaries usually several orders of magnitude lower than the standards prescribed in the Code of Federal Regulations: 10 CFR 20."

This change serves to remove the implication that air leaving mine vent shafts is necessarily within allowable radon concentration levels without further atmospheric dilution.

page 6A.1-54 - paragraph beginning "Chemical. Chemical releases..." - delete the words "are negligible and".

pages 6A.1-61 through 6A.1-66 - Tables 6A.1-9 and 6A.1-10 were extracted from the document "Environmental Survey of the Nuclear Fuel Cycle," November 1972 prepared by the U.S. Atomic Energy Commission, Directorate of Licensing. These tables have been updated in WASH-1248, Environmental Survey of the Uranium Fuel Cycle, dated April 1974. The reader is advised to refer to Tables S-3 and S-3A of WASH-1248 for the revisions to the data presented in Tables 6A.1-9 and 6A.1-10.

page 6A.1-72 - In Coal column, change 2.3 metric tons to read 2.3 million tons.

page 6A.1-73 - The following Note should be added to the footnotes for Table 6A.1-11:

"Note: This Table has been compiled from a different source than Tables 6A.1-9 and 6A.1-10. The LWR values given under ENVIRONMENTAL DEGRADATION differ from the preceding Tables principally because the impacts of the LWR power plant are included here. Also, assumptions used in making calculations differ (e.g. 75% capacity factor vs. 80% capacity factor)."

page 6A.1-82 - References for Section 6A.1-1:

line 1, "Status of" should read "Status and".

Reference 8 should be changed to read:

8. USAEC, Office of Planning and Analysis, "Nuclear Power Growth 1974-2000", Report WASH-1139(74), Washington, D. C., February 1974.

Reference 12 should be changed to read:

12. USAEC, Directorate of Licensing, "Environmental Survey of the Nuclear Fuel Cycle," Report WASH-1248, Washington, D. C., April 1974.

page 6A.1-127 - Insert the following paragraph directly following the first paragraph under 6A.1.4.1.3 Status:

"An evaluation of a conceptual GCFR has been completed by the Regulatory staff. The results are provided in the report, 'Pre-application Safety Evaluation of the Gas Cooled Fast Breeder Reactor', USAEC Directorate of Licensing, Project No. 456, August 1, 1974."

Section 6A.2 - FOSSIL FUELS - Vol. III

page 6A.2-54, Section 6A.2.3.1.1 - First sentence: change the words "about one-third mineral matter" to read "over one-half mineral matter."

page 6A.2-58 - Note: last sentence preceding Section 6A.2.3.1.3; it is not strictly correct to say that "The leasing program's goal ... is ... 1,000,000 bbl ... per day ..." because more acreage than that involved in the leasing program would be required for this rate of production. See page 6A.2-65.

page 6A.2-65, Section 6A.2.3.5 and page 6A.2-67, Section 6A.2.3.7.1 - Note: Cost estimates for shale oil production have risen to approximately four times the cost estimates prevailing at the time the PFES was prepared. Recent estimates are in the range of $11-14 per barrel.

Section 6B.4 - GAS TURBINES - Vol. III

page 6B.4-8, first paragraph, item 4 - delete sentence in parentheses "(Some plants have operated 30,000 hours without maintenance.)" - replace with "(Some plants have operated for about 3,000 hours without maintenance and 10,000 - 20,000 hours without major overhaul.)"

Section 6B.10 - MAGNETOHYDRODYNAMICS - Vol. III

page 6B.10-10 - delete the last sentence of the first paragraph. The sharp rise in fossil fuel costs over the last several years suggest that even the higher efficiency that might be achieved with the successful development of open-cycled fossil-fueled MHD plants might not be sufficient to make this concept economically attractive.

Section 7.2 - CURRENTLY FEASIBLE ALTERNATIVES - Vol. IV

page 7.2-8, fifth line from top of page - insert "but less than 76 ft" after the words "at least 44 ft".

Section 7.4 - SAFEGUARDS - Vol. IV

page 7.4-44 - delete the last sentence preceding section 7.4.7.2.2 and substitute the following:

"A series of regulatory guides has been issued on the subject of physical protection.[16]"

Delete the last sentence in the first paragraph of Section 7.4.7.2.2 and substitute:

"An example is the requirement that transfer of custodial responsibility for SNM be documented."

page 7.4-45 - add the following at the beginning of the first sentence: "Subject to certain exceptions identified in 10 CFR73 ...."

page 7.4-94 - to reference 16 add Regulatory Guides Nos. 5.15, 5.20 and 5.27.

Section 8.2 - FUEL CYCLE ENVIRONMENTAL IMPACT - Vol. IV

page 8.2-4, second paragraph, last sentence - delete "will not" and substitute "are not expected to".

Section 11.1 - FORMULATION OF THE COST-BENEFIT ANALYSIS - Vol. IV

page 11.1-19 - delete the three full paragraphs, and replace with the following two paragraphs:

"As discussed in Section 6, the estimated costs of solar-to-electric power systems are high, generally exceeding $1000/kW(e). In most cases the estimates are for systems that do not incorporate sufficient energy storage capacity to provide a firm power source. Such plants could be valuable as a means of displacing the burning of fuels in conventional power plants. It is concluded, therefore, that solar-to-electric conversion systems have poor prospects for economically competing with coal, nuclear, or geothermal energy for at least several decades.

Most experts agree that the best opportunity for the application of solar energy is in the heating and cooling of buildings. The NSF/NASA Solar Energy Panel estimated that 10% of the thermal energy for buildings could be supplied by solar in the year 2000, and 35% in 2020. This application could displace some electricity that would have been used for space heating, cooling, and water heating in buildings. Based on the NSF/NASA projections of market penetration for the solar heating and cooling of buildings, it is estimated that electricity displacement could amount to 2% in the year 2000, and 5% in 2020. These figures were adopted as representative of a reasonable potential impact of solar energy on electricity demand."

Section 11.2 - ECONOMIC COST-BENEFIT ANALYSIS - Vol. IV

page 11.2-5, third paragraph, third line - "10^9 gigawatts" should read "10^9 watts".

page 11.2-82, paragraph 2, line 2 and page 11.2-128, line 19 - "National" should read "Natural".

Volume V - LETTERS

page V.3-6, line 7 - "Section 11.4.1.1.2" should read "Section 11.1.2.1.1"

page V.3-6, line 8 - "Section 11.3.2.2 "should read" Section 11.1.3".

page V.3-6, line 10 - "Table 11.3-1 and Figure 11.3-1" should read "Table 11.1-6".

page V.15-17, last line of response - "Section 11.2.3.3.3" should read "Section 11.2.4.3.2".

page V.18-19 - response to Comment 4, line 8, "Section 6A.1.1.2.3" should read "Section 6A.1.1.8"

page V.25-35 - response to Comment 4, lines 4 and 5, "Appendix A of Section 11" should read "Appendix IV-B."

page V.25-44 - response to Comment 28, line 2, "Figure 11.2-36" should read "Figure 11.2-19".

Volume VI - LETTERS

page VI.34-22 - response to Comment 2, line 1, "Table 11.2-7" should read "Table 11.2-2".

page VI.34-27 - response to Comment 8. line 3, "Section 11, Appendix A" should read "Appendix IV.B".

page VI.38-339 - response to Comment 2, line 2, "Section 11.3 and 11.4" should read "Sections 11.1 and 11.2". Line 3, "Section 11.4" should read "Section 11.2."

page VI.38-340 - line 1, "Section 11.4.1" should read "Section 11.2". Paragraph 2, line 8, "Section 11.4.1 does demonstrate" should read "Sections 11.1 and 11.2 demonstrate."

page VI.38-344 - response to Comment 9, line 6, "Section 11.2.3 "should read "Appendix IV.B".

page VI.38-381 - last paragraph before NRDC Comment 3 should be deleted. Section 10.4 was not included in the PFES. Material intended for Section 10.4 was incorporated in Section 4.6.

page VI.38-384 - response to second comment, line 1, "Section 11.4" should read "Section 11."

page VI.38-387 - First response, last line, "Section 11.2.4.7" should read "Section 11.2.3.7."

page VI.38-401 - Next to last line, "Section 11.2.3.2" should read "Section 11.2.2."

Volume VII - LETTERS

page VII.42-114 - Response to Comment 9, line 5, "11.2.4.7" should be "11.2.3.7". Last line, "Table 4.1-4" should read "Table 4.1-2."

page VII.42-125 - last line, "460" should be "340".

page VII.42-126 - line 1, "is more than" should read "approaches".

page VII.53-194 - paragraph 4, "Section 11.2.4.2" should read "Section 11.2.3.8".

page VII.53-196 - Response to Comment C.7, line 2, "Section 11.2.4.7" should read "Section 11.2.3.7". Line 3, "References 17 through 25" should read "References 9 through 13."

page VII.53-197 - paragraph 3, line 2, "Section 11.2.4.9" should read "Section 11.2.3.3." Response to Comment 10, line 2, "Section 11.2.3.2" should read "Section 11.2.2."

SECTION III B

SAFETY RESEARCH AND DEVELOPMENT

PROGRAM INFORMATION

INTRODUCTION

Several comment letters on the PFES indicated that certain topics related to the safety of LMFBRs were not fully addressed in Section 4.2.7 of the PFES. More particularly, the comments indicated that the PFES failed to adequately explain the state-of-the-art of LMFBR safety technology, the extensive base of safety information already developed in the R&D program, and the design flexibility which exists to accommodate remaining uncertainties. Accordingly, supplementary material is provided as follows. Much of this material was presented at the Public Hearing on the Proposed Final Environmental Statement for the Liquid Metal Fast Breeder Reactor Program held on May 27-28, 1975, and is included here at the request of the Internal Review Board:

Subsection

III B.1 Additional Information Relative to the RRD Development Plan for LMFBR Safety

III B.2 Additional Information on Energetic LMFBR Core Disruptions

1. General Information
2. Remarks prepared for an ACRS-HCDA Working Group

III B.3 Additional Information on the Basis for Proceeding with the Design, Licensing, and Operation of LMFBRs While the LMFBR Safety Program Progresses

III B.4 Additional Information on LMFBR Risk Assessments Methods Development.

4.2.7S ADDITIONAL INFORMATION RELATIVE TO THE RRD DEVELOPMENT PLAN FOR LMFBR SAFETY

III B.1.1 INTRODUCTION

It should be noted that the following plan is keyed to specified objectives as well as funding and priority assumptions. As with any R&D effort, substantial changes, modifications, clarifications, and redirections can be expected. This is an internal planning document, and cannot by itself be used as a commitment document. Regular and substantial revisions and updates are planned.

The objective of the LMFBR Safety Program is to develop a base of data and analytical tools which will provide input to the LMFBR design process to contribute to the evolution of designs which are safe in all phases of operation, with maximum tolerance for errors and abnormalities, and will provide the basis for an accurate determination of the safety of LMFBRs.

The following objectives have been established by the Assistant Director for Reactor Safety (AD/R) of the Division of Reactor Research and Development, ERDA, in support of the program objective:

1. To provide at appropriate times technical information on safety approaches so that LMFBR plant designers can make rational choices while considering cost, safety and performance.

2. To provide at appropriate times the analytical tools and data base for plant safety analysis of LMFBR's.

3. To support LMFBR plant licensing applications at appropriate times with safety technology.

4. To define and provide required experimental capability for confirmation of analytical tools used in accident analysis and to supplement the data base for fundamental understanding of phenomena for model development.

Plan of Action

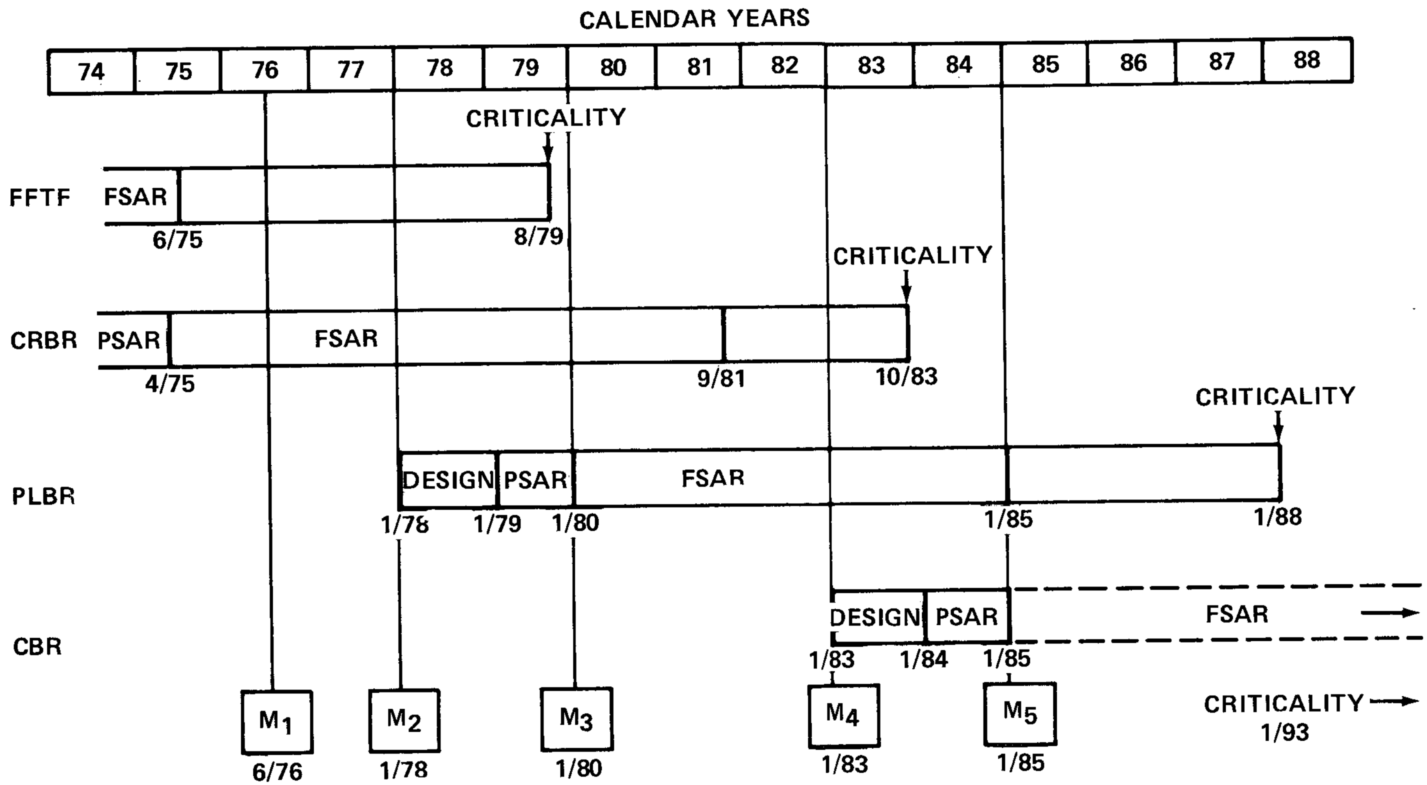
The overall LMFBR Safety Program is projected to extend through the year 2020. Considering the projected schedules for Fast Flux Test Facility (FFTF), Clinch River Breeder Reactor (CRBR) and follow-on plants, five earlier dates have been established on which status of safety technology documentation will be made available by the LMFBR Safety Program as referenceable material in support of projects and in fulfillment of the AD/R objectives. These dates, and their relationship to the projected schedules, are shown on Figure III B-1. The direct and indirect relationship of this status of technology documentation to program needs and to elements of the safety research and development program is indicated schematically on Figure III B-2.

In order to meet the AD/R objectives, a research and development program has been put in place which emphasizes four lines of assurance: prevent accidents, limit core damage, contain accidents in primary system, and attenuate radiological products. The status of technology documentation will delineate and update the extent of our knowledge in each of these four areas at the time of each of the presently established five milestone dates, M1 through M5, on Figure III B-1. It must be recognized that there will be a continuous feed of analytical methods and data into LMFBR program activities from the safety program and that the M1 through M5 dates represent dates on which summary reports are made available. The milestone listing given in the Program Summaries identifies the content and timing of significant completed work packages supporting each of the four lines of assurance.

The necessary work packages will be obtained by pursuing analytical and experimental programs at National Laboratories, industrial contractors, and universities as appropriate. Existing and programmed facilities (TREAT, SLSF/ETR, FFM, OPERA)* dedicated to advanced reactor safety will be utilized; existing and programmed non-dedicated facilities (Power Burst Facility, FFTF) will be investigated for applicability based upon programmatic need and availability; and the need for new facilities will be assessed. When the need for new facilities has been established, projects will be initiated to acquire these facilities. For example, the need for a Safety Research Experiment Facility (SAREF) has been established and SAREF conceptual design studies were initiated in FY 1975.

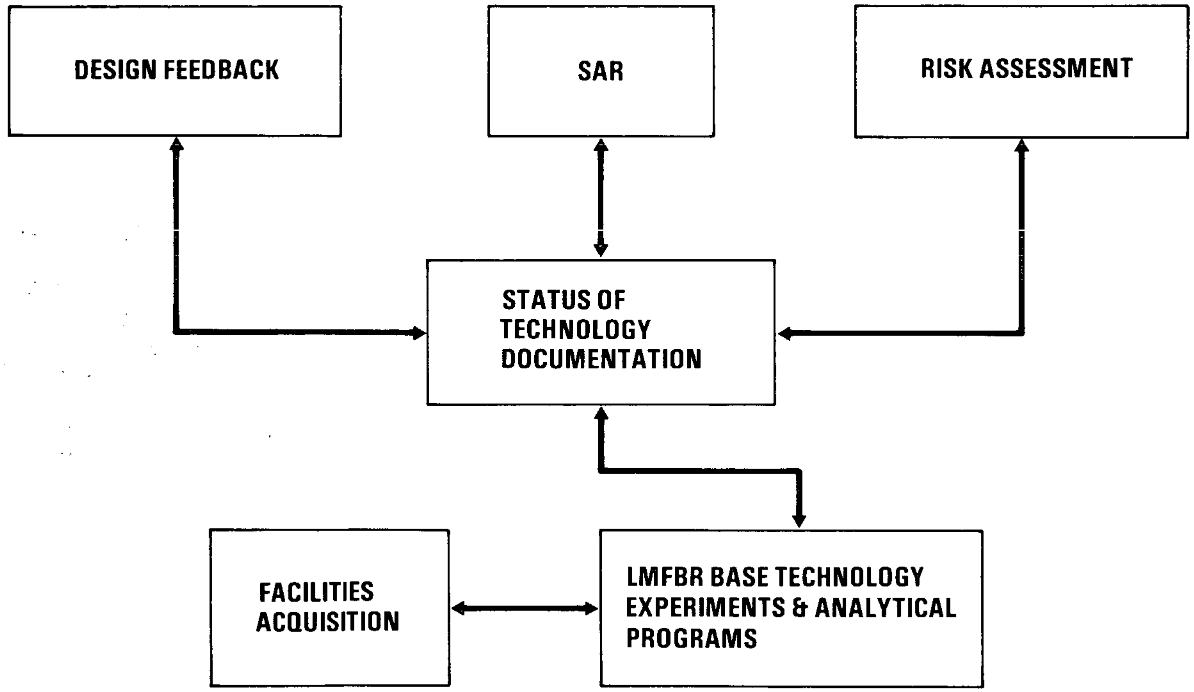
The LMFBR safety research and development program is defined more completely in the three Program Summary documents which follow (LMFBR Safety Analysis, LMFBR Safety Experiments, LMFBR Safety Facilities). Table III B-1, which is a reproduction of Table 11.2-3 of the PFES contains cost estimates of the LMFBR Safety Program. Due to detailed changes in cost projections, rescheduling of facilities, and other factors, this table may not be in complete, detailed agreement with the Program Summaries. However, it is considered to be substantially representative of the cost of the Program.

*Transient Reactor Test, Sodium Loop Safety Facility/Engineering Test Reactor, Fuel Failure Mock-Up, Out-of-Pile Expulsion and Re-Entry Apparatus.



LMFBR SAFETY PROGRAM
MILESTONE TIME SEQUENCING

Figure III B-1



LMFBR SAFETY PROGRAM DOCUMENTATION

Figure III B-2

Table III B-1*

DETAIL OF LMFBR PROGRAM COST PROJECTIONS (1975 thru 2020) LMFBR INTRODUCTION DATE 1987
(millions of fiscal year 1975 dollars)

	FY 1975	FY 1976	3 mos. Trans.	FY 1977	FY 1978	FY 1979	Subtotal 1975-1979	Subtotal 1980-2020	Total 1975-2020
LMFBR									
R&D									
FFTF	65	46	12	46	37	37	243	526	769
CRBR[a]	44	44	12	64	50	33	247	67	314
Support Facilities	43	47	13	60	63	63	289	613	902
Engineering & Technology									
Technology	52	53	15	57	60	63	299	588	887
Engineering	49	53	15	69	94	123	403	759	1162
Cooperative Projects									
CRBR[a]	21	73	5	155	160	140	554	200	754
PLBR[b]				5	18	64	87	189	276
Capital Equipment	19	17	5	23	24	26	114	201	315
Construction Projects									
FFTF	132	74					206		706
Plant Component Test Facility		5		9	41	110	165	203	368
Rad & Repair Eng. Facility				9	18	14	41	5	46
Advanced Fuel Lab				9	18		27		27
Fuels & Materials Exam Facility				23			23		23
Hot Reprocessing Pilot Plant				2	7	28	37	239	276
Miscellaneous Projects	15	18	3	20	28	17	101	91	192
Total LMFBR	440	430	80	551	618	718	2836	3681	6517
Supporting Technology									
Safety									
R&D	37	40	12	46	52	58	245	646	891
Equipment	4	4	2	4	3	4	21	49	70
Construction									
Safety Test Facility		3		9	18	46	76	108	184
Transient Reactor Safety Test Facility				11	9	7	27		27
Advanced Fuel Technology	12	15	5	18	23	28	101	352	453
Total Supporting Tech	53	62	19	88	105	143	470	1155	1625
TOTAL LMFBR & SUPPORT	493	492	99	639	723	861	3306	4836	8142

*NOTE: Due to detailed changes in cost projections, rescheduling of facilities and other factors this table may not be in complete agreement with program summaries. Additionally it does not reflect final Presidential decisions on the FY 77 Budget which are presently pending.

FOOTNOTES FOR TABLE III B-1

[a]The CRBR project has recently completed a major design, cost, and schedule review. The costs reflected here are consistent with the revised cost estimate of $1.7 billion.

[b]The Prototype Large Breeder Reactor (PLBR) is not well defined except that it is expected to be made from large commercial size components. This size would be an extrapolation of 4 to 6 over the CRBR. The funds given here are a very rough estimate of Government assistance; however, a more precise estimate will be available as the nuclear industry approaches the commitment year for this project.

III B.1.2 LMFBR SAFETY ANALYSIS

PROGRAM OBJECTIVES

The functions of the safety organization in the Division of Reactor Research and Development in the area of LMFBR safety analysis are:

1. To provide at appropriate times technical information on safety approaches so that LMFBR plant designers can make rational choices while considering cost, safety and performance.

2. To provide at appropriate times the analytical tools and data base for plant safety analysis of LMFBR's.

3. To support LMFBR plant licensing applications at appropriate times with safety technology.

Program Summary Objectives:

The near term objectives of the analysis element of the LMFBR Safety Program are:

- To complete, by December 1975, the technical data base* for the principal HCDA analyses for the FFTF FSAR

- To complete, by December 1975, the technical data base* for the principal HCDA analyses for the CRBR PSAR

- To provide, by June 1976, a preliminary analytical tool for analyzing postulated CRBR whole core accidents

- To provide, by January 1980, those analytical tools needed to support CRBR FSAR analyses

- To complete, by November 1978, the technical data base* for the principal HCDA analyses for the PLBR PSAR

- To complete, by November 1983, the technical data base* for the principal HCDA analyses for the PLBR FSAR.

*The technical data base is a family of analytical models, computer codes and analytical and experimental data, all appropriately documented in available form for use by interested parties.

JUSTIFICATION

In order to reduce our uncertainties as to the accident characteristics of large commercial LMFBR's, the program will develop a fundamental understanding of the key phenomena controlling the progression of LMFBR accidents, develop mathematical models based on this understanding, and integrate these models into major analytical tools. The earliest models, computer codes and minimal data base used to provide supporting analyses for the FFTF PSAR left substantial uncertainties in assessment. A comprehensive LMFBR safety program is in place to reduce these uncertainties. As outlined in the program objectives, the analysis element is building on that earliest technological base by putting a program in place that will, in a timely fashion, produce improvements in the modeling, computer codes and data base. This program provides for a logical progression in that packaged improvements are planned for the times of submission of the FFTF FSAR, CRBR PSAR, PLBR PSAR, CRBR FSAR, and the PLBR FSAR. Thus the analysis program provides for a step-by-step approach to the timely development and utilization of the analytical tools and data base leading to general acceptance of commercial breeders.

The major LMFBR safety analytical codes, their function, problem solved and planned code improvements are shown in Table III B-2. More detailed information on safety analysis codes and models is available in the documentation listed beginning on page III B-19.

PLAN OF ACTION

In order to meet the AD/R objectives, a research and development program has been put in place which emphasizes four lines of assurance. The analysis element of the LMFBR Safety Program provides analytical methods and data in support of the above research and development program. The objectives of the analysis element will be met by improving the basis and means for reliable analysis of the course of events in LMFBR postulated accidents and the estimated consequences of such accidents. The above will be accomplished (1) by developing the understanding of the basic phenomena needed for analytical modeling of hypothetical accidents; (2) by accumulation of basic data on these phenomena so that the analytical models will have the appropriate realism or conservatism over the desired range of application; (3) by integrating these data and models into complete analytical descriptions of the hypothetical accidents, so that those quantities and parameters important to a review of safety can be accurately determined; (4) by requiring the performance of experiments, so integrated as to test the adequacy of the analytical models to predict accident sequences and consequences, and to thus ensure the model accuracy and completeness; and (5) by application of analytical models to the analyses of generic questions.

Table III B-2

MAJOR ANALYSIS COMPUTER CODES

CODE	FUNCTION	CONTRACTOR	PROBLEM SOLVED	PLANNED IMPROVEMENTS
SAS	To analyze the initiation and continuing propagation of a postulated accident in an LMFBR	ANL	A coupled neutronic-thermal-hydraulic calculation of whole-core LOF/WOS and TOP accident transient behavior up to the point of sub-assembly disruption, prompt criticality, or neutronic shutdown	1. Interface with 2D diffusion and perturbation neutronic code (FX-2) 2. Consistent gas release and sodium voiding in a coolant channel 3. Treatment of multiple primary coolant loops 4. Develop advanced fuel motion, clad motion and fuel-coolant interaction models
MELT	Design to efficiently simulate reactor behavior from postulated accident inception to beginning of core disassembly	HEDL	A coupled neutronics-thermal-hydraulics calculation of whole-core TOP accident transient behavior up to the point of prompt-criticality or neutronic shutdown	Emphasis will be placed on improvements of empirically-based correlations for fuel pin failure
VENUS	To describe the dynamic behavior of an LMFBR reactor core during a disassembly excursion	ANL	A 2-D coupled neutronics-hydrodynamic calculation of whole-core transient behavior resulting from a prompt-critical reactivity insertion	Improve oxide fuel and fission product equation-of-state
PAD	To describe the behavior of a fast reactor subjected to a large reactivity addition in a relatively short time period	LASL	A 1-D coupled neutronics-hydrodynamics calculation of whole-core transient behavior and kinetic energy resulting from a prompt-critical reactivity insertion	Improve models for heat transfer and equation-of-state
REXCO	To calculate reactor structural response to postulated nuclear excursions	ANL	A 2-D Lagrangian coupled hydrodynamic-structural response calculation of primary containment structural response to HCDA pressure loads	Improve slide-line capabilities

Table III B-2 (cont'd)

MAJOR ANALYSIS COMPUTER CODES

CODE	FUNCTION	CONTRACTOR	PROBLEM SOLVED	PLANNED IMPROVEMENTS
ICECO	To calculate reactor component structural response to postulated nuclear excursions.	ANL	A 2-D Eulerian coupled hydro-dynamic-structural response calculation of primary con-tainment and piping structural response to HCDA pressure loads	Incorporate primary piping loop component models
STRAW	To evaluate response of reactor core subassemblies to accident pressure loadings	ANL	A 2-D structural response calculation of subassembly hexcan deformation resulting from local pressurization accidents	Correlate with experiments performed at Stanford Research Institute
SADCAT	To evaluate response of reactor core subassemblies to accident pressure loadings	ANL	A 3-D structural response calculation of subassembly hexcan deformation resulting from local pressurization accidents	Correlate with experiments performed at Stanford Research Institute
SOFIRE	To describe the pressure-time history in a containment environment following a postulated spill	AI	Calculates sodium pool burning dynamics in a heat-transport equipment cell and the resulting temperature and pressure transient in the cell gas	Incorporation of better theoretical and experimentally verified models
SOMIX	To study the transient convective motion of low oxygen gas environ-ments simulating LMFBR heat transfer vaults.	AI	Calculates sodium droplet burning dynamics in a heat-transport equipment cell and the resulting temperature and pressure transients in the cell gas	Incorporate pool burning
CACECO	Assess structural consequences of sodium spray and pool fires in LMFBR equipment and pipeway cells.	HEDL	Calculates the temperature and pressure histories in connected cells resulting from a pool or spray fire in one of the cells	Document code

Table III B-2 (cont'd)

MAJOR ANALYSIS COMPUTER CODES

CODE	FUNCTION	CONTRACTOR	PROBLEM SOLVED	PLANNED IMPROVEMENTS
COMRADEX	To calculate radiological dose at reactor site boundary and beyond.	AI	Calculates the effects of reactor containment and meteorology on environmental radiation exposure resulting from HCDA's	Incorporate improved lung dose models
HAA	To establish containment capability of LMFBR structures to limit aerosol contributions to the site dose.	AI	Calculates aerosol behavior and transport following a HCDA	Develop new aerosol leakage model

The work packages, distributed according to a specific line of assurance, necessary to satisfy the analysis element objectives have been placed with national laboratories, industrial contractors and universities. The assignment of responsibilites to each line of assurance by RRD contractors is shown in Table III B-3.

SCHEDULE

Work in this program will accelerate during the late 1970's, and peak during the 1980's. Completed packages, verified analysis tools and data base, will be required to support the submissions of CRBR, PLBR and CBR SAR's at times designated in Figure III B-1.

The major Safety Analysis milestones leading to the completion of the necessary work packages are as follows:

LOA-1. Prevent Accidents

- No efforts for this LOA under the Safety Analysis program. Such efforts are carried out by specific reactor projects.

LOA-2. Limit Core Damage

- Complete out-of-pile subassembly-to-subassembly damage propagation experiments using simulant high-pressure sources and duct materials to simulate the full range of irradiated SS 316 behavior (6/76).

- Complete initial development of a three-dimensional transient structural response code, (SADCAT), with capabilities for large deformation analysis, fluid interfacing, thermal effects, and long duration accidents, and validate with experiments (6/76).

- Complete integration of heat transfer models into three-dimension transient structural response code (1/77).

- Complete model development for subassembly impact, fracture and fuel pin stress phenomena and integrate into three-dimensional transient structural response code (1/78).

- Extend three-dimensional code capabilities to include the various subassembly geometries considered for large LMFBR cores using advanced fuels (12/79).

Table III B-3

ASSIGNMENT OF REACTOR SAFETY ANALYSIS TASKS BY LINE OF ASSURANCE

LOA*	CONTRACTOR	189a	TITLE
1.	---	---	---
2.	ANL	CA015	Reactor Systems and Containment Structural Response
	ANL	CA049	Subassembly and Reactor Systems Response Modeling
	ANL	CA084	Modeling of Fuel Motion
	ANL	CA085	Modeling of Heat Transfer and Fluid Dynamics
3.	ANL	CA010	Accident Analysis and Safety Evaluation
	ANL	CA015	Reactor Systems and Containment Structural Response
	ANL	CA049	Subassembly and Reactor Systems Response Modeling
	ANL	CA084	Modeling of Fuel Motion
	ANL	CA085	Modeling of Heat Transfer and Fluid Dynamics
	LASL	AL009	Models and Computer Modules for Processes in Reactor Disassembly Analysis
	LASL	AL010	Analysis of and Studies Relating to Hypothetical Fast Reactor Reactivity Induced Power Transients
	GE	SG002	Safety Engineering
	HEDL	FF061	Fast Reactor Safety Analysis
	NWU	CX017	Liquid-Liquid Surface Impaction
	BYU	CX002	Fast Reactor Safety Analysis Techniques
	HNL	OH069	Neutronics Analysis of Disrupted Cores
	HNL	OH099	Central Computerized Data Base for LMFBR Safety Codes
4.	ANL	CA015	Reactor Systems and Containment Structural Response
	ANL	CA085	Modeling of Heat Transfer and Fluid Dynamics
	HEDL	FF061	Fast Reactor Safety Analysis
	SRI	SX005	Experiments in Bubble Transport Phenomena

*LOA - Line of Assurance
1. Prevent Accidents
2. Limit Core Damage
3. Contain Accidents in Primary System
4. Attenuate Radiological Products

LOA-3. Contain Accidents in Primary System

- Formulate improved model for clad flooding and entrainment criteria (4/75).

- Complete preliminary extended motion disassembly model (6/75).

- Complete comparison of several disrupted core behavior computer codes through use of "benchmark" calculations (9/75).

- Evaluate thermal interaction effects (fuel-steel-sodium) on extended fuel motion and recompaction recriticality (1/76).

- Complete scale-model, simulant material primary containment response modeling experiments for validation of codes (6/76).

- Complete improvements in explicit Lagrangian code, (REXCO), for high-energy nuclear excursions and validate with experiments (6/76).

- Complete treatment of low-energy nuclear excursions with implicit Eulerian code, (ICECO), and validate with experiments (6/76).

- Complete initial coupling of explicit Lagrangian and implicit Eulerian codes (REXCO and ICECO), for treatment of full range of nuclear excursion energies (6/76).

- Complete scale-model, simulant material primary loop piping and component structural response modeling experiments for validation of codes (6/76).

- Complete initial development of an implicit Eulerian code, (ICEPEL), for structural response analysis of arbitrary pressure pulses within primary coolant loops containing valves, elbows, pumps and heat exchangers, and validate with experiments (6/76).

- Complete studies on sensitivity of primary containment structural response to non-axisymmetric geometrical configurations and extend analytical capabilities to account for three-dimensional interaction phenomena (1/77).

- Complete development of implicit Eulerian code for analysis of primary coolant system structural response and integrate with coupled Lagrangian-

Eulerian primary containment structural response code for consistent treatment of complete primary system (6/77).

- Complete formulation of an implicit Eulerian code for the analysis in a consistent way of the dynamic and thermodynamic phenomena associated with the generation and in-vessel transport of high-pressure multi-phase materials resulting from nuclear excursions (1/78).

- Complete development of a Lagrangian-Eulerian primary system structural response code with an integrated capability for analysis of the mechanical, dynamic and thermodynamic phenomena associated with the generation and motion of the high-pressure products resulting from a nuclear excursion (12/79).

- Formulate incoherent voiding model, provide initial assessment for loss of flow conditions at uniform power and compare with TREAT L series experiments (1/78).

- Integrate model for incoherent voiding and clad relocation (3/78).

- Comparison integrated model of incoherent voiding and clad relocation with experimental data (6/78).

- Integrated model for the effect of non-condensable gases on coolant motion (6/78).

- Complete preliminary model of fission gas effects on early fuel motion (1/78).

- Define conceptual model for fuel transport (3/78).

- Characterization of fragmentation and plugging phenomena as it relates to fuel transport and integration of these phenomena into a fuel transport model (6/78).

- Model development for dispersive mechanisms in transition phase analysis (1/78).

- Complete preliminary model detailing interaction with surrounding material structure (1/78).

- Integration of a fuel mechanics code (pre-failure phenomena) with a fuel transport model (post failure phenomena) (1/80).

- Extension of the fuel mechanics code to advanced fuels (1/80).
- Model for combined clad and fuel motion for large reactors (1/80).
- Correlation of fuel transport model with experiments (1/80).
- Integration of fuel transport model with fuel mechanics code (1/80).

LOA-4. Attenuate Radiological Products

- Develop methods for producing high-pressure vapor bubbles and conduct scoping tests to demonstrate that bubble surface instabilities and inertial effects are not likely to result in rapid jetting of bubble constituents to cover gas region (9/75).
- Conduct small scale experiments using high-pressure vapor sources in water to assess inertial effects of bubble expansion from constrained geometries and effect of structures on bubble dynamics and breakup (6/76).
- Complete analysis and documentation of the radiological consequences of an HCDA in the FFTF (9/75).
- Complete analysis and documentation associated with design basis sodium spills in FFTF to determine the adequacy of design to accommodate large sodium spills (9/75).
- Begin a comparison study on containment versus confinement using already available radiological assessment tools (1/76).
- Complete and issue a plan for integrating, through standard interfaces and sub-routines, radiological effects codes (6/76).
- Model aerosol production due to mechanical break-up of the two-phase expansion process, vapor condensation, and further coalescense or fragmentation in the cooling process (1/78).
- Model aerosol release rates through reactor head openings, condensation within the primary vessel, and radioactivity release from the primary vessel (1/79).

CONTRIBUTING PROGRAMS

The program effort is supported by base technology development being conducted by the Engineering & Technology Office. This supporting base technology development is principally in the areas of basic physical property data, fuels performance data, basic neutronic data and development of instrumentation. Basic physical property data is supported by the following:

189a	CONTRACTOR	TITLE
02681	ANL	Materials Properties for Fuel Performance Predictions
10567	HNL	Mechanical Properties for Structural Materials
02162	ANL	Thermophysical Properties of Reactor Fuels
10556	ORNL	High Temperature Design
12212	HEDL	Ceramic Fuels Properties and Behavior
12666	HEDL	LMFBR Fuel Cladding Information Center

Fuel performance data by the following:

12160	HEDL	Fuel Pin Transient Performance
12161	HEDL	Fuel Pin Steady State Performance Limits
12401	HEDL	Irradiation Units-GETR
12779	HEDL	Fuel Pin Transient Overpower Limits
12667	HEDL	Fuel Performance Analysis and Prediction
13820	GE	Fuel Cladding Interaction
07401	LASL	Examination of Fast Breeder Reactor Fuels
07463	LASL	High Performance LMFBR Fuel
07548	LASL	Uranium-Plutonium Mixed Carbide Fuels

Basic neutronic data by the following:

03110	BNL	Reactor Cross Sections Evaluations
06019	ANL	FBR Physics Constants

Development of instrumentation by:

02665	ANL	Neutron Detector Channel Development
13644	AI	Sodium System Leak Detection
13643	GE	Instrumentation Development

CODE AND MODEL DOCUMENTATION FOR SECTION III B.1.2

SAS CODES AND MODELS

SAS1A

- J. C. Carter, G. J. Fischer, T. J. Heames, D. R. MacFarlane, N. A. McNeal, W. T. Sha, C. K. Sanathanan, and C. R. Youngdahl, "SAS1A, A Computer Code for the Analysis of Fast Reactor Power and Flow Transients," ANL-7607 (1970), Argonne National Laboratory, Argonne, Illinois.

SAS2A

- F. E. Dunn, G. J. Fischer, T. J. Heames, P. Pizzica, N. A. McNeal, W. R. Bohl, and S. M. Prastein, "The SAS2A LMFBR Accident Analysis Computer Code," ANL/RAS 73-39 (1973).

SAS2D

- F. E. Dunn, "SAS Code Development," ANL-RDP-24, (January 1974).

SAS2B

- M. G. Stevenson, W. R. Bohl, F. E. Dunn, T. J. Heames, G. Hoppner, L. L. Smith, "Current Status and Experimental Basis of the SAS LMFBR Accident Analysis Code System," Proc. of the Conf. on Fast Reactor Safety, Beverly Hills, California (April 1974).

SAS/DEFORM-II

- A. Watanabe, "The DEFORM-II Mathematical Analysis of Elastic, Viscous, and Plastic Deformation of a Reactor Fuel Pin," ANL-8041 (1973).

SAS Multiple Bubble Slug Ejection Coolant Voiding Model

- F. E. Dunn, G. J. Fischer, T. J. Heames, and P. A. Pizzica, "A Multiple Bubble Slug Ejection Model for Coolant Voiding," Trans. Am. Nucl. Soc., 14 (1) 241 (1971).

Film Motion Voiding Model

- G. Hoppner and F. E. Dunn, "Sodium Film-Model in SAS2A Voiding," Trans. Am. Nucl. Soc., 16 (2) (November 1973).

- G. Hoppner, "Sodium Film Motion Model of SAS3A," ANL/RAS 74-22 (September 1974).

Fuel Motion Model, SLUMPY

- W. R. Bohl and M. G. Stevenson, "A Fuel Motion Model for Loss-of-Flow," ANL/RAS 74-18 (August 1974).

- H. V. Wider, et al., "An Improved Analysis of Fuel Motion During an Overpower Excursion," Proceedings of the Fast Reactor Safety Meeting, Beverly Hills, California (April 1974).

Clad Relocation Model, CLAZAS

- W. R. Bohl and T. J. Heames, "A Clad Motion Model for LMFBR Loss-of-Flow Accident Analysis," Trans. Am. Nucl. Soc., 16, 358 (1973).

- W. R. Bohl and T. J. Heames, "CLAZAS: The SAS3A Clad Motion Model," ANL/RAS 74-15 (August 1974).

Primary Loop Hydraulics

- F. E. Dunn, "Initiating Accident Code Development," ANL-RDP-2, (February 1972).

Fuel-Coolant Interaction

- L. L. Smith, J. R. Travis, M. G. Stevenson, F. E. Dunn, and G. J. Fischer, "SAS/FCI, A Fuel-Coolant Interaction Model for LMFBR Whole-Core Accident Analysis," Proc. Topical Meeting on Mathematical Models and Computational Techniques for Analysis of Nuclear Systems, CONF-730414-P1, Ann Arbor, Michigan (April 9-11, 1973).

REXCO/ICECO CODES AND MODELS

REXCO-H and -HEP:

- Y. W. Change and J. Gvildys, "REXCO-HEP: A Two-Dimensional Computer Code for Calculating the Primary System Response in Fast Reactors," to be published during 1975 as ANL report.
- J. Gvildys and Y. W. Chang, "REXCO-HEP Users Manual," ANL/RAS 75-1, January 1975.
- Y. Chang, J. Gvildys and S. Fistedis, "Two-Dimensional Hydrodynamics Analysis for Primary Containment," ANL-7498, November 1969.
- G. Cinelli and J. Gvildys, S. Fistedis, "Inelastic Response of Primary Reactor Containment to High-Energy Excursion," ANL-7499, November 1969.

  J. Gvildys and S. Fistedis, "Inelastic Response of Primary Reactor Containment to High-Energy Excursions," ANL-7499, Supplement, June 1971.

REXCO-HT:

- T. J. Marciniak, "Heat Transfer Problems in LMFBR Containment Analysis," ANL-8037, July 1973.
- T. J. Marciniak and J. C. Bratis, "Improvements in REXCO-HT," to be published in 1975.
- J. C. Bratis, T. J. Marciniak, "Reactor Structural Response to Molten-Fuel-Coolant Interactions," invited paper E1/4, 2nd Intl. Conf. on Structural Mechanics in Reactor Technology, Berlin, 1973.
- C. Y. Wang, et al., "An Implicit Finite Difference Method for Fluid Dynamics Calculation in the Primary Coolant Systems," ANS Topical Meeting on Mathematical Computation Methods April 1975, Charleston, S. C.
- M. T. A. Moneim, "ICEPEL, A Two-Dimensional Computer Program for the Transient Analysis of a Pipe-Elbow Loop," to be published during 1975 as an ANL report.

VENUS CODES AND MODELS

- W. T. Sha and T. H. Hughes, "VENUS: A Two-Dimensional Coupled Neutronics-Hydrodynamics Computer Program for Fast-Reactor Power Excursions" ANL-7701, October 1970.

- J. F. Jackson and R. B. Nicholson, "VENUS II: An LMFBR Disassembly Program," ANL-7951, September 1972.

STRAW/SADCAT CODES AND MODELS

- J. M. Kennedy and T. Belytschko, "Energy Source and Fluid Representation in a Structural Response Code--STRAW," ANL-8140 (November 1974).
- D. F. Schoeberle, et al., "Implicit Temporal Integration for Long-Duration Accidents in a Structural Response Code--STRAW," ANL-8136 (October 1974).
- J. M. Kennedy, "Nonlinear Dynamic Response of Reactor-Core Subassemblies," ANL-8065 (January 1974).
- A. H. Marchetas and T. B. Belytschko, "Nonlinear Formulation for Transient Analysis of Three Dimensional Thin Structures," ANL 8104, June 1974.

MELT CODES AND MODELS

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- A. E. Waltar, A. Padilla, and R. J. Shields, "MELT-II, A Two-Dimensional Neutronics-Heat Transfer Program for Fast Reactor Safety Analysis," HEDL-TME-72-43, Hanford Engineering Development Laboratory, April 1972.
- W. T. Sha and A. E. Waltar, "An Integrated Model for Analyzing Disruptive Accidents in Fast Reactors," Nucl. Sci, Eng. 44, 135-156 (1971).
- B. G. Gniting and F. E. Bard, "PECT-2T: Test Analysis of Hot-Cal-II Transient Test," HEDL-TME-74-15, April 1974.
- F. E. Ward, "PECT-1, A FORTRAN-IV Computer Program for Determining the Plastic-Elastic Crrep and Thremal Deformation in Thick Walled Cylinders," BNWL-1171, December 1969.
- F. E. Bard and D. S. Dutt, "PECT-2 Analysis of H3 Transient Test," HEDL-TME-72-28, February 1972.
- D. S. Dutt and R. B. Baker, "SIEX--A Correlated Code for the Prediction of Liquid Fast Breeder Reactor (LMFBR) Fuel Thermal Performance," HEDL-TME-74-55, September 1974.
- A. E. Waltar, et al., "MELT-III, A Neutronics, Thermal Hydraulics Computer Program for Fast Reactor Safety Analysis," HEDL-TME-74-47, October 1974.
- P. Beiriger, et al., "SOFIRE-2 User Report," AI-AEC-13055, March 30, 1972.
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III B.1.3 LMFBR SAFETY EXPERIMENTS

PROGRAM OBJECTIVES

The functions of the reactor safety organization in the Division of Reactor Research and Development in the area of LMFBR safety experiments are:

1. To provide at appropriate times technical information on safety approaches so that LMFBR plant designers can make rational choices while considering cost, safety and performance.
2. To provide at appropriate times the analytical tools and data base for plant safety analysis of LMFBR's.
3. To support LMFBR plant licensing applications at appropriate times with safety technology.

Program Summary Objectives:

Consistent with the Assistant Director's plan of action specific objectives are enumerated in the four major areas of Accident Prevention, Limiting Core Damage, Containing Accidents in Primary System, and Attenuating Radiological Products. Advanced fuel program objectives are also addressed. The timing of the major first level objectives has been identified in the AD Program Plan. It should be noted that complete and convincing success in any one of these areas would provide an adequate assurance for the safety of LMFBRs. Recognizing the role of uncertainties, and the need for design flexibility, a sound and defensible set of lines of assurance is sought.

1. Prevent Accidents - To develop a viable accident prevention line of assurance by providing sets of data and an associated rationale which will provide a means of demonstrating that all conceivable LMFBR core disruptive accidents can be made to have a sufficiently low probability of occurrence that they need not be considered as a basis of design.
    a. To resolve by January 1976 safety questions regarding rapid blockages and rapid fuel element failure propagation for UO_2 fuel in LMFBR designs.
    b. To establish by January 1977 an engineering basis for utilizing selected inherent safety features which can prevent or limit core damage during postulated accident sequences.

2. Limit Core Damage - To develop a viable subassembly containment line of assurance by providing data and rationale necessary to demonstrate that core disruption can be contained within the individual subassemblies even when low

probability but mechanistically possible failures of the accident prevention line of assurance are postulated.

a. To establish by January 1978 an understanding of fuel pin failure mechanisms, instrumentation, energetics, mechanical consequences, fuel pin material transport, and sustained shutdown coolability sufficient to support a particular set of design objectives directed toward containment of all mechanistically postulated accident sequences within individual subassembly domains.

3. Contain Accidents in Primary System - To develop a viable whole core involvement line of assurance by providing data and rationale necessary to demonstrate that there is not a substantial hazard to the public even should extensive core disruption and subsequent core disassembly be presumed.

   a. To establish by January 1978 the data and rationale necessary to demonstrate a defendable upper limit on disrupted core energetics, as a function of selected generic core nuclear design parameters.

   b. To provide by January 1978 the data necessary to establish design adequacy of mechanical structures within the defendable upper limit energetics envelope, as a function of selected generic design parameters for core internals.

   c. To provide by January 1978 the data necessary to demonstrate ultimate coolability of disrupted fuel debris under condition of substantial core disruption as a function of selected generic core debris parameters.

4. Attenuate Radiological Products - To develop a viable radiological assessment line of assurance by providing data and rationale necessary to demonstrate that the radiological consequences of an envelope of postulated accident sequences can be accommodated without significant hazard to the public.

   a. To establish by January 1978 the data and rationale necessary to establish and support realistic upper-limit bounds for the quantity of generation of plutonium aerosols during certain postulated LMFBR core disruptive accidents.

   b. To establish by January 1978 the data and rationale necessary to assess the attenuation of plutonium and fission products during transport from the core region to the containment building and from the containment building to the site boundary.

   c. To demonstrate and proof-test by January 1978 emergency containment air-cleaning systems as may be appropriate to mitigate radiological consequences of core disruptive accidents.

5. Other Fuels - The above objectives are independent of reactor fuel system. The above milestones, at present, only apply to the mixed oxide LMFBR plants. A program plan for other fuels is under development.

JUSTIFICATION

In accordance with the AD Program Plan the objectives of the LMFBR Safety Experiments Program Summary are directed toward establishing the base of data and analytical tools which will permit safe and economically viable designs and provide the bases for establishing public confidence in the overall safety of LMFBR's.

BACKGROUND

Traditionally, design and development activities have pursued a defense in depth strategy associated with the prevention and mitigation of postulated accident sequences. Analytical tools based on first principle understanding are developed and validated by appropriate experimental programs so that the consequences of postulated accident sequences may be analyzed. The probability of initiation of postulated accident sequences coupled with the predicted consequences guide the research and development programs which are conducted either to lower the probability of initiation or to mitigate the consequences of the postulated event. The safety program is organized to provide a high degree of visibility as to status and progress in these interrelated efforts.

In the area of accident prevention major progress has been made in establishing the understanding necessary to design reactor systems which have a very low probability of major accident initiation. Potential initiators of reactivity and flow perturbations have been identified and accommodated in design. Thus far the program has produced an adequate understanding of the value of the Doppler coefficient and the benign nature of sodium superheat. There is consensus that rapid blockages and rapid propagation of fuel pin failures can be shown not to be a concern. The primary emphasis of this line of assurance is presently focused on establishing the relative probability of events postulated to lead to an accident so that the strength of the line of assurance may be assessed more quantitatively. Important open questions are the quantitative reliability of the plant shutdown system, the decay heat removal system and structures.

In the area of accident mitigation, there is general consensus that LMFBR fuel-coolant interactions are benign. Progress has been made in establishing fuel pin failure mechanisms and understanding early clad and fuel motion. This understanding permits investigation of design alternatives which have potential for mitigating postulated accidents without resort to arguments which involve whole core considerations. These investigations have begun. Important open questions are the quantitative understanding of fuel motion including the conditions under which fuel sweepout can occur.

A demonstration that accidents involving a whole core meltdown can be accommodated requires an ability to place an upper bound on recriticality energetics, demonstrate tolerable mechanical damage, demonstrate final coolability of the core debris, and assess resulting radiological consequences. Substantial progress has been made in assessing the consequences of these postulated accident situations. The program has established understandings of some features of the energy partition and structural effects that might result from major core disruptions. The potential for energetic recriticality has been somewhat reduced as a result of the understanding of the benign nature of fuel-coolant interactions. Understanding of debris bed behavior is adequate to provide significant guidance in the design for post accident heat removal. Information exists to estimate post accident distribution of core debris but not in a mechanistic way. The currently dominant open questions are characteristics of extensive and extended fuel motion and the uncertainty in the upper limit which can be placed on the energetics of potential recriticality. Facilities and/or experiments which can provide design guidance other than current broad envelope understanding are being studied but are not yet in the inventory.

Major uncertainties and associated conservatisms are presently associated with radiological assessments. Some progress has been made in understanding aerosol behavior (there is an existing code named HAA III) and a base of technology for ex-containment fission product transport exists from previous water reactor experience. However, additional data to assess the type and amount of radioactive substances released from the fuel and the attenuation mechanisms thence to release from containment should be developed to permit improved assessment capability.

The 189a's which support this element of the LMFBR Safety Program Plan are described in Table III B-4.

PLAN OF ACTION

A plan of action has been established for developing a strong line of assurance in each of the four areas identified. The plan of action calls for progressively stronger lines of assurance with corresponding design flexibility for successive LMFBR projects through the commercial breeder. The R&D efforts have also been

Table III B-4

OBJECTIVES OF 189A'S FOR LMFBR SAFETY EXPERIMENTS PROGRAM

189a #	Contractor	Program Objectives
CA012	ANL	Provide high temperature physical property data on sodium, steel, and mixed oxide fuel for use in LMFBR accident analyses.
CA019	ANL	Determine distribution of core debris following an LMFBR core disruptive accident and assess capability to remove decay heat in-vessel and ex-vessel.
CA021	ANL	Replacement of damaged fuel in TREAT.
CA033	ANL	Identify safety issues associated with advanced fuels in LMFBR's and define efforts necessary to resolve the issues.
CA053	ANL	Develop information on the mechanical response of nuclear fuel to "accident" thermal transients.
CA066	ANL	Define the failure dynamics and mechanism under transient flow conditions by conducting in-pile and out-of-pile experiments using the Sodium Loop Safety Facility.
CA081	ANL	Provide engineering and operations support for in-pile experiments in TREAT.
CA082	ANL	Study fast reactor fuel and coolant behavior under transient conditions associated with fuel failure by conducting in-pile experiments in TREAT.
CA083	ANL	Study fast reactor coolant dynamics, fuel clad coolant interactions, and fuel motion by conducting out-of-pile experiments.
CA088	ANL	Investigate ways of mitigating HCDA consequences through the design of inherently safe cores.
CC003	CE	Study carbide fuel safety issues and develop programs, data and methods for safety analysis of cores using carbide fuel.
CW077	WARD	Develop LMFBR core design modifications to protect or mitigate core damage due to postulated accidents.
CW078	WARD	Develop reliability requirements and goals for LMFBR shutdown systems and define rationale for implementing requirements on CRBRP.
FF052	HEDL	Provide an assessment of the current status of technology in selected safety areas and recommend programmatic changes.

Table III B-4 (cont'd)

OBJECTIVES OF 189A'S FOR LMFBR SAFETY EXPERIMENTS PROGRAM

189a #	Contractor	Program Objectives
FF127	HEDL	Provide experimental data base, data analysis and analytical model development necessary to quantify the basic mechanisms of fuel pin transient response for use in LMFBR safety analysis.
FF132	HEDL	Provide fuel for in-pile test program.
FF134	HEDL	Develop and large-scale proof test an air cleaning system suitable for use under LMFBR design basis accident conditions.
OH044	HNL	Perform ex-reactor experiments on flow in LMFBR fuel rod bundles including effects of blockages, pipe breaks, and flow coastdown.
RX003	RL	Maintain surveillance of CSE vessel in the 221-T facility.
SA002	AI	Develop and verify codes to assess consequences of sodium releases; investigate the release of fuel and fission products from burning sodium; determine aerosol behavior for HCDA analyses.
SA018	AI	Develop core design that will prevent or mitigate accidents to levels acceptable for maintaining public health safety through inherent properties and for characteristics of design.
SG017	GE	Examine feasibility of in-vessel and ex-vessel heat removal systems for large masses of molten fuel and establish functional design requirements for such systems.
SG019	GE	Develop models to permit assessment of radiological consequences of LMFBR accidents.
SG031	GE	Identify and evaluate LMFBR core design concepts with improved inherent safety characteristics.
SG032	GE	Experimental and analytical efforts to gain understanding of the mechanisms of accident induced fuel failure and subsequent consequences.
SG033	GE	Assure that LMFBR shutdown system goals are consistent with plant protective system objectives and to assure that component reliability is related to shutdown system reliability.

organized so that cost benefit trade off decisions can be made among the four areas with regard to the related R&D effort and the potential payoff in an LMFBR design.

1. Prevent Accidents

In the area of accident prevention efforts will continue to obtain data and develop the rationale necessary to demonstrate that the probability of occurrence of all conceivable core disruptive accidents in an LMFBR is sufficiently low so that these accidents need not be considered a basis of design. The development of this line of assurance is being accomplished via three efforts.

The first effort is to: (a) determine the reliability requirements for engineered safety features incorporated in designs necessary to eliminate the need for considering core disruptive accident; (b) determine the reliability of as-designed engineered safety features; and (c) provide results of items (a) and (b) to designers for incorporation into design activities. These efforts are being conducted at General Electric and Westinghouse under 189a nos. CW078 and SG033 respectively.

The second effort to develop this line of assurance is to obtain the understanding required to limit faults locally to the involvement of individual fuel pins. These efforts are being conducted at General Electric and HEDL under 189a nos. SG032 and FF127, respectively, Argonne National Laboratory under 189a nos. CA081, CA082, and CA083, and at HNL under 189a OH044. The basic thrust of these programs is to 1) demonstrate that rapid fuel element failure propagation will not occur by demonstrating all postulated rapid propagation mechanisms to be benign; 2) demonstrate that a sufficiently large blockage of a subassembly is benign so that proper design of fuel element inlet and outlet can make rapid blockage sufficiently low in probability that it need not be considered as a basis of design; and 3) demonstrate that slow blockage mechanisms propagate sufficiently slowly that instrumentation can provide adequate warning to shut down the plant safely. It is anticipated that technical agreement concerning the benign nature of rapid blockage and fuel element failure propagation can be established and documented by January 1976. The plan to address slow blockage mechanisms has not yet been completed but will incorporate accumulation of operating experience (foreign and domestic) as part of the International Working Group on Fast Reactor Safety activities in Fuel

Failure Mechanisms and investigation of instrumentation techniques in ongoing experimental programs such as FFM, SLSF, and TREAT.

The third effort is to attempt to develop inherently safe features which would utilize the inherent characteristics of materials and/or designs to fully prevent core disruptive accidents. These efforts are currently being conducted at Westinghouse, General Electric, Argonne National Laboratory and Atomics International under 189a nos. CW077, SG031, CA088, and SA018 respectively. These efforts will lead to a selection of promising concepts during 1975 and will establish by January 1977 the engineering basis for designing selected inherent safety features which can prevent or limit core damage during postulated accident sequences.

2. Limit Core Damage

The cost and time required to demonstrate experimentally that energetic recriticality is inherently precluded, coupled with the increased difficulty of demonstrating post accident heat removal with larger core sizes, provides substantial incentive to place additional emphasis on a subassembly containment line of assurance. This line of assurance can be strengthened by increased mechanistic understanding of early phases of accident sequences which are being provided through efforts conducted at GE, HEDL under 189a's SG032 and FF127 respectively and at ANL under 189a's CA081, CA082, CA083 and CA066 using TREAT, SLSF and foreign reactors. These efforts coupled with an increased understanding of inherent safety features which will be provided in 189a's CA088, CW077, SG031 and SA018 will provide the basis for developing this line of assurance. Also, increased use of diagnostic instrumentation appropriate to large plants will be incorporated in experiments to develop an understanding of characteristic signals of failure sequences and response times of detecting instrumentation. These techniques augmented by additional refinements in post accident heat removal which will be accomplished by ANL in 189a CA019 will begin to provide new design options in the 1978 time frame. It is anticipated that SLSF will be upgraded to a test size capability of 61 pins in 1977. This test size will provide a greater capability to understand and utilize incoherencies within a test bundle in establishing this line of assurance. Further refinements in all of the above understandings can be expected from a more prototypic (size & spectrum) test environment such as that planned for SAREF.

3. Contain Accidents in Primary System

In the area of accident mitigation, efforts will continue to strengthen the whole core involvement line of assurance by demonstrating a reduced potential for energetic recriticality and by increasing mechanistic understanding of heat removal. Planning for the experimental program which will be required to demonstrate a reduced potential for recriticality will be conducted by ANL as a subtask of 189a CA013. Out-of-pile experiments will be planned and conducted by ANL as a subtask in 189a CA083 to increase fundamental understanding of controlling phenomena. Planning for and conduct of experiments to enhance understanding of post accident heat removal will be accomplished by ANL in 189a CA019. In 189a SG017 GE will provide by July 1975 a recommendation for an engineering option of ex-vessel post accident heat removal.

While some of the experiments conducted by ANL under 189a CA066 in the Sodium Loop Safety Facility (SLSF) will contribute to the above efforts, it is likely that larger test size will also be required to reduce the need for the conservatism in existing designs, which can lead to improved economics. Efforts to establish feasibility and cost of a safety test facility of improved capability (SAREF) are being conducted by GE and ANL under 189a's SG038 and CA045, respectively. ANL will also investigate as a subtask of 189a CA013 the potential of other approaches to demonstrate the reduced potential for energetic recriticality.

4. Attenuate Radiological Products

In the area of radiological consequence assessment, efforts will continue to develop an in-vessel source term model which will semi-mechanistically track the transport and attentuation of fuel and fission products from the core region through the sodium to the cover gas region and through leak paths in the reactor vessel head to the containment building. Attenuation credit will be evaluated for condensation of sodium vapor and condensible fission product vapors onto liquid sodium and structures. Credit for fuel and fission product aerosol fallout and plateout will be assessed, for the transport through the sodium and in the cover gas region. Modeling efforts, definition of experimental needs, and overall coordination will be accomplished by GE under 189a SG019. Supporting experiments will be conducted by AI under 189a SA002 and by SRI under 189a SX005.

In addition, efforts will continue to improve models and conduct confirmatory experiments for sodium fire analysis, aerosol behavior, and radiological dose assessments. Basic modeling efforts will be accomplished by GE under 189a SG019 and AI under 189a SA002. Supporting experiments for sodium fires and aerosol behavior will be conducted by AI under 189a SA002 and by HEDL under 189a FF134.

Efforts have also been initiated to develop emergency containment air cleaning systems and to proof-test such systems on an engineering scale. Laboratory scale tests will be conducted (contractor to be selected) to permit initial system concept selection. Proof testing will be accomplished by HEDL under 189a FF134.

5. Advanced Fuels

The above plan of action applies to the efforts required for mixed oxide LMFBR reactor plants. The plan of action for other fuel systems involves first the identification of differences between mixed oxides and each other candidate LMFBR fuel system and then determining the implication of these differences on the safety of LMFBR reactors using these fuel types. This is then to be followed by determining and resolving those safety issues that are critical to the viability of commercial reactors using such a fuel system. The above efforts are being conducted at ANL and Combustion Engineering under 189a No. CA033 and CC003 respectively. It is expected that other organizations will also assist in completing the efforts required to resolve the safety issues. This plan of action applies to the development of all four lines of assurance.

MAJOR FACILITIES REQUIREMENTS

Major facilities used or anticipated to support the LMFBR safety experimental program are described in the Section III B.1.4.

SCHEDULE

Schedule of major activities and key milestones are provided in Tables III B-5 through III B-9.

CONTRIBUTING PROGRAMS

The LMFBR Safety Experiments Program interfaces with the LMFBR Safety Facilities Program and therefore indirectly interfaces with all contributing programs described therein. In addition, the Assistant Director for Engineering and Technology conducts programs in fuel development R&D which interface with and

Table III B-5

LMFBR SAFETY PROGRAM - MAJOR PROGRAMMATIC MILESTONES

. Complete Documentation of Technical Base for FFTF FSAR and CRBR PSAR (M1)[a]	June 1976
. Establish Technical Base for PLBR Conceptual Design (M2)	January 1978
. Establish Technical Base for CRBR FSAR (M3)	January 1980
. Establish Technical Base for PLBR FSAR (M4)	January 1983
. Establish Technical Base for CBR Conceptual Design (M4)	January 1983
. Establish Technical Base for CBR FSAR (M5)	January 1985

[a]See Figure III B-1 for milestone time sequencing

Table III B-6

LMFBR SAFETY PROGRAM - KEY MILESTONES
LINE OF ASSURANCE 1

. Resolve Safety Questions for FFTF and CRBR Regarding Blockages, Rapid FEFP, and PAHR from Debris Beds	January 1976
. Recommend Inherent Safety Design Features and Development Requirements	June 1976
. Establish an Engineering Basis for Designing Safety Features	January 1977

Table III B-7

LMFBR SAFETY PROGRAM - KEY MILESTONES
LINE OF ASSURANCE 2

. Establish Understanding of Fuel Sweepout	January 1976
. Complete Upgrading of FFM to 61 Pin Capability	March 1976
. Complete Initial Development of SADCAT Code	June 1976
. Complete Duct Melt-through Tests	December 1976
. Establish Understanding of Fuel Failure Mechanisms	January 1978

Table III B-8

LMFBR SAFETY PROGRAM - KEY MILESTONES
LINE OF ASSURANCE 3

. Complete Construction of SLSF (Conduct P I)	October 1975
. Complete Preliminary Modeling of Fuel-Steel-Sodium Thermal Interaction Effects	January 1976
. Complete Small Scale UO_2 - Stainless Steel Boil Up Experiments	June 1976
. Complete Initial Coupling of REXCO and ICECO Codes	June 1976
. Provide Design Basis for Molten-Fuel Retention System	1977
. Complete Large Scale UO_2 - Stainless Steel Boil Up Experiments	1977
. Define Conceptual Model for Fuel Transport	March 1978
. Correlate Fuel Transport Model With Experiments	January 1980
. Determine Final Disposition and Coolability of Fuel Debris (for large plants)	1984

Table III B-9

LMFBR SAFETY PROGRAM - KEY MILESTONES
LINE OF ASSURANCE 4

• Initiate Containment - Confinement Trade-Off Study	January 1976
• Complete Initial Bubble Dynamics Experiments	June 1976
• Complete Scoping Tests for Plutonium Aerosol Source Term	June 1976
• Complete Simple Conservative In-Vessel Transport Model	June 1976
• Establish Basis for Aerosol Leakage Attenuation	June 1976
• Establish Basis for Aerosol Depletion in Meteorological Models	June 1976
• Establish Feasibility and Credit for Air Cleaning System	June 1977
• Establish Insoluble Nature of Plutonium and Sodium Aerosols	June 1977
• Establish Head Seal Leakage for Alternative Designs	January 1978
• Complete Proof Tests of Air Cleaning Systems	June 1979

support reactor safety R&D. Also, the Division of Reactor Safety Research in NRC conducts studies and experiments which are monitored for usefulness to LMFBR Safety Experiments objectives.

DOCUMENTATION FOR SECTION III B.1.3

Additional current information on the LMFBR Safety Experiments Program may be found in the topical and progress reports listed below.

•	AI-AEC-13144	AI Quarterly Technical Progress Report Nuclear Safety Characterization of Na Fires and Fast Reactor Fission Products
•	GEAP-14034-1	Radiological Assessment Models, Dec. 1974
•	GEAP-14038-1	Advanced Safety Analysis - Quarterly Report
•	ANL-RDP-28 thru	Reactor Development Program Progress Report
•	ANL-RDP-38	
•	ORNL-TM-4729	Quarterly Progress Report on Reactor Safety Programs Sponsored by the Division of Reactor Safety Research for Liquid-Metal Cooled Fast Breeder Reactor Safety
•	HEDL-TME-74-3	HEDL Quarterly Technical Report

III B.1.4 LMFBR SAFETY FACILITIES

PROGRAM OBJECTIVES

The function of the reactor safety organization in the Division of Reactor Research and Development in the area of LMFBR safety facilities is to define and provide required experimental capability for confirmation of analytical tools used in accident analysis and to supplement the data base for fundamental understanding of phenomena for model development.

Program Summary Objectives:

Facility capability requirements and their relationship to overall LMFBR safety program objectives are discussed in the LMFBR Safety Experiment Program Summary. Program Summary objectives discussed below are associated with meeting the experimental requirements defined in that summary. These requirements are in addition to the basic requirement that the facility be capable of depositing sufficient energy in the test specimen (currently specified as 2800 joules/gm total energy) to simulate maximum postulated accident scenarios.

1. Size - To provide test capability sufficiently prototypic in size to permit understanding of controlling size dependent phenomena within a subassembly during the progression of postulated accident sequences.

   a. To provide out-of-pile test capability at FFM for full sized prototypic LMFBR subassembly tests on the schedule indicated.

37 pins	6/76
61 pins	4/77
91 pins	11/77
217 pins	8/78

   b. To provide out-of-pile capability at OPERA to simulate a full sized subassembly on the schedule indicated.

15 pins simulating 61	10/75
36 pins simulating 169	6/76

   c. To provide in-pile test capability of up to 61 prototypic LMFBR fuel pins in SLSF in the schedule indicated.

19 pins	9/75
37 pins	6/76
61 pins	7/77

d. To provide in-pile test capability of 1 to 4 full sized subassemblies in SAREF by the mid 1980's.

2. Spectrum - To provide prototypic neutron flux test environment in SAREF by the mid 1980's.

3. Period - To provide prototypic (1-5 msec) transient rate test environment by the mid 1980's.

4. Experiment Duration - To provide prototypic experiment test duration on the schedule indicated.

SLSF	9/75
SAREF	mid 1980's

5. Preconditioning - To provide capability to study effects of preconditioning on the schedule indicated.

Establish PBF Feasibility	12/75
PBF (potential)	12/76
SAREF (potential)	mid 1980's

6. Facility Alternatives - To define by March 1976 the complete inventory of safety test facility capability necessary to establish economically viable LMFBR designs in the mid 1980's.

   a. Integral Test - To provide the option and/or capability to perform an integral test on the schedule indicated.

Complete feasibility study	6/75
Follow on milestones	TBD*

   b. Super Treat - To define by March 1976 the facility requirements additional to those incorporated in SAREF and determine the need for additional transient test capability.

JUSTIFICATION

A stronger line of assurance at the accident prevention level can be established with additional statistical data base and applicable operating experience. Traditionally

*TBD - To be determined

this line of assurance alone has not been adequate to provide desired levels of assurance of safety. Additional accident mitigating features have been incorporated in reactor designs to provide additional levels of assurance.

As discussed in the LMFBR Safety Experiments Program Summary the existing inventory of test facilities cannot provide the prototypicality to establish a mechanistically oriented line of assurance within the subassembly. Some of the same facility limitations do not permit further reductions in the presently employed conservatisms associated with establishing a line of assurance for whole core involvement or subsequent radiological consequences assessment. Facility improvements and/or new facilities are required to provide improved prototypicality in the areas of size, neutron spectrum, transient period, and experiment duration.

Additional test capacity will also be required as advanced fuels testing programs develop.

BACKGROUND

The status of LMFBR safety technology (including important open questions) is summarized in Sections III B.1.2 and III B.1.3. The understanding reflected therein has largely resulted from bench scale experiments and experiments conducted in out-of-pile facilities OPERA and FFM and the TREAT in-pile facility. Background information on these and other facilities discussed herein is supplied beginning on page III B-45.

Discussed in this element of the LMFBR program are the efforts to extend facility capability to meet the experimental requirements defined in Section III B.1.3.

Major new scheduled facility additions and modifications include the SLSF/ETR, which initiated testing in October 1975, and the increase in capacity of the FFM from 37 to 61 full power pins, which is scheduled for completion in December 1975. (Actual FFM testing schedule is shown on page III B-36.) In addition, the PBF facility is now operational and could provide a test bed for a meaningful series of experiments incorporating preconditioned fuel pins.

As is discussed in the Background and Plan of Action in Section III B.1.3 the capability available in the above facilities substantially limits the long range LMFBR experimental program. Continuing studies on safety testing facilities resulted in a decision in early CY 1974 to investigate feasibility of a Safety Test Facility (STF) which could extend existing experimental capability to study phenomena encompassing larger experiment size, harder neutron spectrum, higher transient rates and longer experiment duration as related to LMFBR safety analyses.

In September 1974, ANL completed an initial study which was sent to essentially the entire LMFBR community for comment. Heavy emphasis was placed on soliciting and incorporating input from regulatory organizations. Based on input received, two initial conceptual design studies of an STF concept are being conducted by ANL and GE. The concept being studied has been named the Safety Reactor Experiment Facility (SAREF). The milestone for completion of the two parallel conceptual design studies of SAREF is December 1975. When conceptual design studies are completed, design criteria will be written and an Architect-Engineer contractor selection will be made. The standard sequence for facility design and construction will be pursued.

The plan of action to use existing and scheduled facility capability is described in the following section. The 189a's which support this element of the LMFBR Safety Program Plan are described in Table III B-10.

Table III B-10

OBJECTIVES OF 189A'S FOR LMFBR SAFETY FACILITY PROGRAM

189#	Contractor	Program Objectives
CA013	ANL	Define the in-pile experimental needs for a safety test facility.
CA045	ANL	Develop a conceptual design, and to provide a conceptual design report, for the Safety Research Experiment Facility.
(SG038)	GE	Develop a conceptual design, and to provide a conceptual design report, for the Safety Research Experiment Facility.

NOTE: Other facility support is accomplished as an integral part of the experimental program and is reflected in the experimental program. (See Section III B.1.3)

PLAN OF ACTION

The objective of this element of the LMFBR Program Plan will be achieved by the completion of facilities which are now in construction; by conduct of studies to identify new facility needs; by modification and upgrading of existing facilities and by design and construction of needed new facilities.

Under 189a CA013, ANL will provide basic planning and analysis to define experimental requirements and assess priorities with regard to obtaining desirable improvements in test capability in advanced facility designs and modifications.

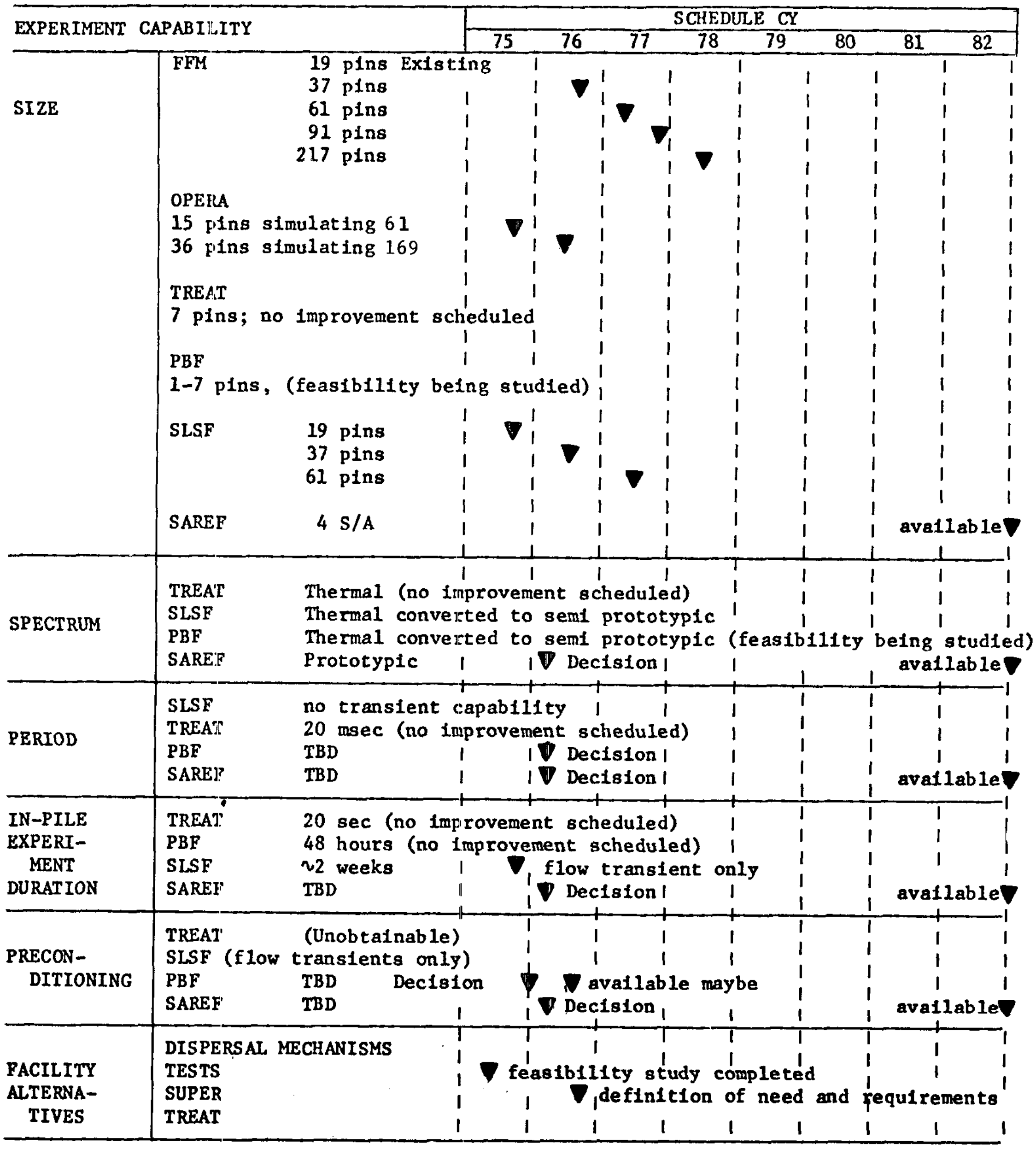
As shown in Figure III B-3 and Table III B-11, the facilities planning and acquisition activities provide an orderly progression in experimental capability leading to progressively stronger lines of assurance. The present planning anticipates that adequate lines of assurance can be provided with viable economic impact in the mid 1980's.

The plan of action as related to the program summary objectives is:

1. Experiment Size - Experiment size is a very important consideration in prototypic test capability which offers potential for studying phenomena which can mitigate postulated core disruptive events. Subassembly temperature distributions and the subassembly wall provide interesting additional margin to remove fuel benignly in postulated unterminated disruptive events. Understanding these effects can also narrow the range of uncertainties associated with subsequent postulated whole core involvement. For this reason a concentrated effort has been put in place to understand size effects on a subassembly scale.

   A study has been conducted by ANC under 189a IA016 to define requirements to upgrade SLSF to 61 pin capability. It appears that extensive modifications will not be required and the upgrading is scheduled for completion in August 1977. This capability will be available to support M_3 objectives.

   FFM capability at ORNL is presently being upgraded under 189a OH044 from 19 to 61 pin capability (scheduled for completion in October 1975). This capability will be available to study thermal hydraulics effects of incoherencies in temperature distribution and will support SLSF in-pile experiments. Simultaneously in the OPERA loop, ANL under 189a CA083 is investigating feasibility of thermal-hydraulically modeling large bundles with triangular arrays. A comparison of FFM and OPERA results will provide guidance on the feasibility of in-pile triangular test arrays which provide one option to investigate effects of scale in existing facilities (TREAT and SLSF).



LMFBR SAFETY FACILITIES
SCHEDULE OF MAJOR ACTIVITIES

Figure III B-3

Table III B-11

LMFBR SAFETY FACILITIES
LIST OF MAJOR MILESTONES

Provide FFM 37 pin out-of-pile capability	8/76
Provide SLSF 19 pin in-pile capability	9/75
Provide OPERA 15 pin (simulating 61) out-of-pile capability	10/75
Establish PBF feasibility for preconditioning	12/75
Provide FFM 61 pin out-of-pile capability	4/77
Provide OPERA 36 pin (simulating 169) out-of-pile capability	6/76
Provide SLSF 37 pin in-pile capability	6/76
Provide FFM 91 pin out-of-pile capability	11/77
Provide SLSF 61 pin in-pile capability	7/77
Provide FFM 217 pin out-of-pile capability	8/78
Provide SAREF capability	1/83

While some effects of scale can be studied as outlined above (especially early stages of the postulated events) many phenomena such as heat transfer processes in substantially disrupted geometries are better studied with greater prototypicality in such areas as surface to volume ratios. Consequently, studies are underway by GE and ANL under 189a's SG038 and CA095 respectively, to determine the feasibility and cost associated with providing greater test size capability. At the same time, the options to provide more prototypic neutron spectrums, transient rate and experiment duration are being examined As mentioned earlier, conceptual designs of such a safety test facility, SAREF, are being prepared by GE and ANL. Conceptual designs anticipate that the facility can be in operation by 1982. Experiments in SAREF can therefore support M_4 and M_5 objectives. (See Section III B.1.1)

2. Spectrum - TREAT, the only operating in-pile test facility utilizes a thermal driver core. SLSF also will utilize a thermal driver core. Test spectrums in these facilities can be hardened by the use of filters but prototypic hard neutron flux spectrums cannot be obtained and substantial experimental compromise is required.

Studies have been made to modify TREAT with a converter section in the core to provide a more prototypic flux spectrum. This remains an open option which is not actively being pursued at this time.

The proposed new Safety Test Facility (SAREF) would provide a prototypic hard neutron spectrum.

3. Period - Transients for some postulated LMFBR accident scenarios are in the 1-5 msec range. SLSF will have no transient capability and TREAT can only provide a transient environment down to ~20 msec. PBF can potentially provide an environment with a 5-10 msec period but the proof tests to establish feasibility have not been conducted. A high priority is being established to negotiate the necessary arrangements with NRC to accomplish these proof tests on PBF in FY 1976. If experiments in the lower period ranges prove to be feasible in PBF it is intended to conduct tests on preconditioned fuel which overlap existing data in period and extend to the lower feasible periods in PBF. A schedule for these tests will be developed at ANL as a subtask of 189a CA081.

   There is also a question of potential for fuel-coolant interaction (FCI) at the lower period (higher transient rates) which remains open. NRC proposes to accomplish small scale (gms of UO_2) tests in the Annular Core Pulsed Reactor (ACPR) at Sandia. The specifics of this test capability are not yet defined. There is some uncertainty that these tests can close the issue.

   As a result of the above, low period testing will be an important requirement in SAREF and further efforts will be expended by ANL in 189a CA013 to assess the probability of successful resolution of the FCI issue with existing facilities and the corresponding priority of the requirement for SAREF.

4. Experiment Duration - An extended experiment duration is desirable to build into the test specimen prototypic fission product decay energy, to establish prototypic thermal-hydraulic initial conditions, and to precondition the test fuel. Of the two available in-pile facilities, SLSF has an extended experiment duration capability (~2 weeks max.) but no transient capability while TREAT has a transient capability but only an ~30 sec experiment duration capability. This combination leaves gaps in the required test capability.

5. Preconditioning* - The potential use of PBF to investigate the effects of preconditioning and with transients in the 5-20 msec range is being studied by ANL under 189a CA081. Feasibility has not yet been established.

6. Facility Alternatives - Under 189a CA013 ANL will continue to study experiment capability requirements. Also reviews with NRC, LASL, Sandia, and reactor vendors will be continued to establish facility capability requirements with the constraining criteria being the establishment of economically viable design options in the mid 1980's.

   a. Special purpose experiments - alternate and/or additional options to the SAREF concepts are being studied under ANL 189a CA013. The objective of such tests would be consolidating and demonstrating the current belief that the potential for energetic recriticality during a core disassembly is extremely low due to the physical conditions which exist in the core during the disassembly process. If such experiments are undertaken now, it is projected that they would contribute to meeting milestone M_3, and subsequent objectives.

   b. Super TREAT - It is anticipated that it may not be economically or technically attractive to construct a SAREF facility with flexibility to provide complete coverage of the broad range of capability required in advanced safety test facilities. It is planned to optimize SAREF on a cost-benefit basis considering other options available -- i.e. use of or modifications to existing facilities and/or construction of new special purpose facilities. An additional consideration will be the increased test capacity required for testing advanced fuels.

   These considerations make it appear at this time that an improved facility of the TREAT class (primarily in size and flux spectrum) could be required. Decision on this alternative will be made in March 1976 in conjunction with the selection of a SAREF concept.

*When irradiated fuel is removed from a reactor and cools, cracking of the fuel occurs. Preconditioning refers to a short steady state irradiation period in a reactor prior to transient testing in order to heal the cracks and obtain more prototypic fuel conditions.

MAJOR FACILITIES

Major facilities used or anticipated to support the LMFBR safety program are described below. Additional information on each of these facilities may be found in the documentation listed on page III B-50.

TREAT:

1. Location - Idaho National Engineering Laboratory

2. Contractor - Argonne Universities Association and The University of Chicago (Operators of Argonne National Laboratory)

3. Startup Date - September 1959

4. Description - The Transient Reactor Test (TREAT) facility is an adiabatic (uncooled during transient) thermal heterogeneous reactor test facility designed to evaluate reactor fuels and structural materials under conditions simulating various types of nuclear excursions and transient undercooling situations. Fuel meltdown, thermal interaction between overheated fuels and coolant, and the transient behavior of ceramic fuels for high-temperature systems can be studied. The TREAT reactor is also available for neutron radiography.

5. Shared Use - The facility is used approximately 67 percent of the time for safety with remaining time being utilized by the Office of Engineering and Technology.

6. Capability -
   a. Size - full length fuel pins
   b. Spectrum - Thermal
   c. Period - ∿20 msec
   d. Experiment duration - ∿30 full power sec.
   e. Preconditioning - No
   f. Energy deposition during transient - 2000-3000 MW-sec. (600°C max. fuel temp.)

SLSF/ETR:

1. Location - Idaho National Engineering Laboratory

2. Contractor - Argonne Universities Association and The University of Chicago (Operators of Argonne National Laboratory)
   Aerojet Nuclear Corporation

3. Startup Date - September 1975 (scheduled)

4. Description - The Sodium Loop Safety Facility (SLSF) is a complete in-pile sodium test facility capable of testing up to 37 full sized pins in the Engineering Test Reactor (ETR). The SLSF is capable of providing prototypic thermal-hydraulic simulation of present generation LMFBR reactor cores. The nuclear test conditions are determined by the ETR reactor which provides the neutron environment.

5. Shared Use - The ETR will be utilized 100% for SLSF tests until 1982 at which time the Gas Reactor In-pile Safety Test Facility (GRIST) will begin to utilize the ETR approximately 33 percent of the time with increasing utilization to ∿67 percent in 1985.

6. Capability -
   a. Size - presently 37 full length fuel pins; 61 full length fuel pins being studied.
   b. Spectrum - thermal
   c. Period - None (steady state flow transient).
   d. Experiment Duration - ∿2 full power weeks.
   e. Preconditioning - Yes
   f. Energy deposition during transient - None

PBF:

1. Location - Idaho National Engineering Laboratory

2. Contractor - Aerojet Nuclear Corporation

3. Startup Date - Undetermined for LMFBR tests.

4. Description - The Power Burst Facility (PBF) was designed to provide experimental data which will aid in defining the behavior of nuclear fuels in off-normal operating conditions. The PBF reactor can be operated in three modes which are: (1) a steady-state mode with power levels up to 40 MW; (2) a natural power burst mode which yields reactor periods as short as 1.3 msec. and power peaks as large as 240 GW; and (3) a shaped burst mode resulting in energy generations up to 1500 MW-sec. Because of this versatility, the PBF can provide power and energy densities in test fuel

rod clusters that are analytically derived for a broad spectrum of postulated reactor accidents.

5. Shared Use - The PBF facility is presently dedicated to NRC light water reactor safety programs but negotiations and studies are underway to use PBF for short period and/or preconditioning tests on LMFBR fuel.

6. Capability -
   a. Size - 1-7 full length fuel pins.
   b. Spectrum - thermal.
   c. Period - 1.3 msec design but not demonstrated.
   d. Experiment duration - Essentially indefinite.
   e. Preconditioning - Yes.
   f. Energy deposition during transient - TBD*.

FFM:

1. Location - Holifield National Laboratory

2. Contractor - Union Carbide Corporation (Operator of Holifield National Laboratory)

3. Startup Date - April 1971

4. Description - The Failed Fuel Mockup (FFM) is an electrically heated sodium test facility in which out-of-pile testing can be performed with electric cartridge heaters that simulate the fuel pins in a portion of an LMFBR fuel assembly. In experiments carried out in FFM the behavior of the simulated partial subassembly under blockage and other test conditions of LMFBR interest can be studied, and information on thermal and hydraulic characteristics of various subassembly configurations may be obtained. The FFM capability is presently being extended from 19 pins to 61 full power pins with the flexibility to eventually provide a test capability of a full subassembly (217 pins).

5. Shared Use - FFM is presently fully utilized by LMFBR safety programs. In the past some testing was conducted in support of the Office of Engineering and Technology in the area of thermal-hydraulic performance in steady state operation.

*TBD - to be determined

6. Capability -
   a. Size - 19 full length fuel pin simulation with greater capability scheduled up to 217 pins.
   b. Spectrum - N/A
   c. Period - N/A
   d. Experiment duration - Indefinite.
   e. Preconditioning - N/A

OPERA:

1. Location - Argonne National Laboratory

2. Contractor - Argonne Universities Association and the University of Chicago (Operators of Argonne National Laboratory)

3. Startup Date - September 1972

4. Description - The OPERA (Out-of-pile Expulsion and Re-entry Apparatus) is used for sodium expulsion and re-entry tests. The objective of these tests is to obtain information on coolant behavior following flow transients such as flow coastdown and partial or complete inlet flow blockage. Fuel pins are simulated by cartridge heaters capable of producing a uniform or axial varying heat flux. The test section design incorporates certain flexibility which allows performance of flow transients with several different characteristics.

5. Shared Use - The OPERA facility is utilized 100 percent for LMFBR safety programs.

6. Capability -
   a. Size - 15 full length fuel pin simulation with 36 pin capability scheduled.
   b. Spectrum - N/A
   c. Period - N/A
   d. Experiment Duration - Essentially indefinite.
   e. Preconditioning - N/A

SAREF:

1. Location - TBD

2. Contractor - TBD

3. Startup Date - Mid 1980's.
4. Description - SAREF will be a facility which can extend experimental capability to study phenomena encompassing larger experiment size, harder neutron spectrum, higher transient rates and longer experiment duration.

5. Shared Use - Initial use will be 100 percent LMFBR safety program. Shared use with the GCFR safety program is expected to develop.

6. Capability - (Design Objectives)*
   a. Size - 4 full length LMFBR subassemblies.
   b. Spectrum - Prototypic
   c. Period - 1-5 msec.
   d. Experiment Duration - Indefinite.
   e. Preconditioning - Yes

CONTRIBUTING PROGRAMS

The Assistant Director for LMFBR Facilities Support manages TREAT and ETR operations and manages the construction of major construction projects such as SLSF. The Office of Reactor Safety Research Coordination (under the Assistant Administrator for Environment and Safety) operates PBF as a dedicated facility for NRC**. Irradiation services are obtained from EBR-II and GETR. FFTF will also provide irradiation services when it comes on line.

*It has been determined that the design objectives for size and spectrum can be obtained. It has not been determined that capabilities, c, d and e can be fully obtained.

**NRC also is modifying the Annular Core Pulse Reactor (ACPR) at Sandia for short period testing of small samples of fuel material and is conducting safety test facility studies at LASL.

DOCUMENTATION FOR SECTION III B.1.4

- (OPERA) R0101-1000-SA-01 "System Design Description for the Out-of-Pile Expulsion and Re-entry Apparatus," April 1973.
- (FFM) ORNL-TM-3656 "Final Systems Design Description of the Failed Fuel Mockup of the LMFBR," September 1972.
- (PBF) UC-80 "Final Safety Analysis Report for PBF," Part 1, July 1971.
- (TREAT) ANL/RAS 72-23 Appendix A, B, C "TREAT Baseline Description Document."
- (SLSF) ANL/RAS 72-11 "Safety Analysis Report for FEFP In-Pile Loop in Experimental Test Reactor," April 1972.
- (SLSF) ANL/RAS 71-40 "Preliminary System Design Description of the Fuel Element Failure Propagation In-Pile Loop System," December 1971.
- (SAREF) ANL/RAS 74-23 "ANL Findings and Recommendations on LMFBR Safety Testing Needs and Acquisition of New In-Pile Testing Facilities," March 1975.

III B.2

4.2.7.8S ADDITIONAL INFORMATION ON ENERGETIC LMFBR CORE DISRUPTION

III B.2.1 ERDA STAFF RESPONSES TO THREE QUESTIONS POSED BY INTERNAL REVIEW BOARD

a. What is the nature of the R&D effort?

b. How does it fit into the sequence of events in the overall LMFBR program? What impact will completion of this R&D have on LMFBR designs?

c. How is incompleteness of R&D taken into account in reaching the conclusion that we should proceed?

A more extensive discussion of the question of the potential elimination of HCDA core energetics is provided in the attached statement to an ACRS HCDA subcommittee.

General Discussion

The nature of the R&D effort is to (1) identify and eliminate all potential initiators of serious accidents and (2) provide design characteristics and engineered safety features to mitigate the consequences of all accidents which are postulated to proceed through the in-depth protective defenses which have been established.

The safety R&D fits into the sequence of events in the overall LMFBR Program in two ways. First, R&D is conducted to define the essential properties and characteristics of the LMFBR system which are required to provide a safe envelope of operation with only a general regard to economic considerations. Secondly, additional R&D is performed to narrow the uncertainties and increase the design options available to the designer so that the economics of the LMFBR systems may be improved.

Incomplete R&D is taken into account on each LMFBR reactor project by providing sufficient design margins and engineered safety features to safely encompass uncertainties which exist.

Specific Discussion

a. Nature of R&D

(1) Identification and Elimination of Initiators:

One of the principal avenues being investigated and the one that leads to the greatest safety payoff is the prevention of any initiating event progressing into a very severe accident. It is clear that this is an effective and complete solution. It requires specific elimination of power-coolant mismatch situations and the design of an LMFBR lends itself well to these specific design approaches. Sodium is an excellent heat transport fluid and the large inventory of low pressure sodium coupled with redundant heat transport loops makes very unlikely a loss-of-coolant accident situation. Mechanisms for potential energy-producing reactivity addition can be identified and controlled through known design techniques.

Early safety R&D efforts have established an understanding of the inherent negative Doppler coefficient which can protect the plant against postulated reactivity insertions. All mechanistically conceivable reactivity additions can be designed to be accommodated within the Doppler control and the redundant independent reactor shutdown systems which terminate the postulated accident sequence.

The only primary mechanism discussed today wherein an LMFBR would be subject to an energetic dispersal is a large scale sudden and violent ejection of sodium coolant. Associated R&D has established the benign nature of sodium superheat and sodium and gas voids as initiators of damaging reactivity addition mechanisms in a properly designed LMFBR. With respect to potential flow transients, R&D has demonstrated the ability of the fuel subassembly to accommodate large sudden blockages. Proper design of the subassembly inlet and outlet can thereby eliminate the potential of sudden damaging blockages. Also, R&D efforts have investigated postulated initiators of rapid fuel element failure propagation and shown them to be nonpropagative. All evidence of long term operational failures of test fuel elements have shown such slow failures to be benign in nature also.

As a result of the R&D program, no initiating mechanism for a core disruptive event of any sort in an LMFBR has been identified which does not involve a failure to scram. Therefore, LMFBR designs provide redundant and independent reactor shutdown systems that will terminate accident initiating events, thereby maintaining the core in a stable geometry, cooled by one of several cooling systems. Additional time and operating experience of other reactors will be available to further strengthen this case for plants following CRBR. Further, except for LMFBR designs in which a large positive reactivity worth zone could be suddenly and coherently voided as a result of a loss of flow accident accompanied by a total loss of control function, there is no possible initiator of an energetic core disruption prior to large scale loss of core integrity.

(2) Provision of Design Characteristics and Engineered Safety Features: Since there are some uncertainties in the quantitative data to support the absolute value of the extremely low probability of accident initiators, R&D efforts are being undertaken at several contractor sites to show there is no damaging energy release possible from LMFBR accidents, including those which may involve total loss of core integrity. The FFTF was designed to accommodate the effects of a postulated core disruptive accident. Disruptive events are also being discussed relative to CRBR.

In addition to R&D related to core disruptive energetics, R&D is also performed in areas to support LMFBR projects' ability to provide adequate design margins to accommodate core disruptive events. R&D programs are conducted to demonstrate (1) that the energy releases in this type of event are limited, (2) that the ensuing mechanical consequences can be accommodated in the design and (3) that the final disposition of the core debris is coolable.

With regard to limited energetics there are three basic components in the establishment of the case against energetics. In order to get an energetic excursion other than by primary means (sodium voiding, discussed above), it is necessary to have three factors: first, more than one large, dense fuel mass; second, a mechanism for rapidly and coherently assembling these masses; and third a means of converting fission heat energy into mechanical work. Based on current knowledge for specified designs, it is possible to demonstrate an upper bound on the energetics associated with a core disruptive event. Early calculations which were performed in a grossly conservative way indicated that large energetics in a disrupted core required high density core masses to be accelerated together with a large degree of coherence.

Early R&D efforts were focused on demonstrating the lack of accelerating mechanisms (other than gravity). The largest such accelerating mechanism was the postulated fuel-coolant interaction which has been demonstrated to have much lower energy conversion efficiency than that required to produce energetic recriticality. Other potential accelerating mechanisms such as chemical interactions were also investigated. These investigations have shown all such postulated accelerating mechanisms to be benign in nature. It is, therefore, essentially precluded that the large coherent acceleration necessary for an energetic recriticality will occur for such postulated disruptive events.

The above argument rests on the lack of any large coherent acceleration mechanisms despite searches for some such effect. The case appears to be even stronger in that the high density core masses assumed in present calculations are not physically realizable in a real reactor system. This is believed to be the case because the temperature of molten UO_2 is above the boiling point of stainless steel. The large inventory of stainless steel intermixed with the melting UO_2 would "boil up" and disperse the UO_2 thereby reducing the effective density. Even without the steel or other volatiles such as fission products, fuel vapor appears capable of causing an early boil-up. Out-of-pile experiments are underway to investigate this phenomena. In-pile experiments will also be conducted as appropriate to strengthen this argument.

The third factor is that of a working fluid. Without an efficient heat transfer to an efficient working fluid (e.g. sodium), little mechanical damage could be generated. All empirical data to date indicate very low efficiency energy transfer, thus vastly reducing the damage potential. R&D conducted in the past has led to decreasing estimates of the energetics which are possible in core disruptive events. Because of the conservatism which still exists in these estimates, future R&D will decrease the estimated energetics even further.

Reiterating, it appears that none of the indicated conditions are met. The required fuel masses would never be present. There are no effective accelerating means to assemble separated masses; and if energy were so generated, it would not be effective in causing mechanical damage. The only question is one of establishing that base of data and experience to ensure that no exception lies undetected.

Given the magnitude and nature of the energetics described above, it is a relatively straightforward design problem to design the primary system to accommodate the energy release even using extremely conservative assumptions. The design techniques have been verified by experimental tests in scaled models up to one-tenth scale.

b. Timing of Safety Research Relative to Overall LMFBR Program

As noted above LMFBR safety R&D has helped establish bases for the design of FFTF and CRBRP. When compared to what is actually expected, both of these plants provide substantial safety margins and design features to provide a demonstrably safe operating envelope.

The timing of future LMFBR safety R&D is oriented toward three objectives:

(1) Provide further data and support for the FSAR of the CRBRP to improve the quality of the safety arguments.

(2) Provide substantially different design options for the PLBR which provide potential for improving the quality of safety analyses and/or economic enhancement.

(3) Provide additional data and options for improved safety analyses and/or economic enhancement of the CBR.

Upon completion of those developments necessary to establish that energetics form no reasonable part in a safety and licensing assessment, a variety of design flexibilities will be available to the designer. The massive mechanical strengths now built into reactor structures may give way to more functional and flexible approaches. Fuel handling, refueling, and control functions in particular may be substantially simplified, taking advantage of the low pressure primary system. Further, the only serious concern for large scale LMFBR plutonium contamination accidents arises from possible vaporization of plutonium in an energetic HCDA. Without energetics, there can be no vaporization.

c. Taking Account of Uncompleted R&D

While the output of the safety research and development program may be expected to provide guidance in safety assessment, appropriate consideration of other major factors must be included in a judgment as to the adequacy of the safety of a plant and the required effort on R&D. These include considerations of design, analytical methods, material, equipment, process variables, fabrication, construction, quality assurance, inspection, testing, maintenance, repair and operation. The activities undertaken in the R&D program cannot, of themselves, assure or negate the safety of a reactor. The results of the safety R&D program, structured as it is toward understanding the potential effects of defects and errors, and many postulated off-design, abnormal and emergency conditions, including the postulated bypassing of many plant monitoring and operator corrective actions, represent only one of many major inputs which must necessarily be part of the overall assessment of reactor design and reactor safety.

While the accumulated information in nuclear technology, as in any other body of knowledge, is not without gaps and uncertainties in the accuracy of data, there are many options available in design, engineering and operation of nuclear plants to compensate for uncertainties and to reduce associated risks to acceptably low values. Redundancy in components and instruments, conservative engineering practices providing substantial margins, safety devices and systems, fission product barriers, and a wide range of choices in operating parameters can all be used to produce safe and reliable plants. Similar options in engineering and operational practices are available to resolve additional questions that may arise during construction and testing and over the operating life of a nuclear facility.

The existence of areas where knowledge is incomplete does not mean that appropriate criteria and evaluation models cannot be established for evaluating safety adequacy. Safety evaluations can be performed using calculations that characterize the expected behavior, together with margins based on conservative assumptions where knowledge is incomplete. This procedure establishes reasonable bounds on phenomena under consideration or otherwise provides an adequately conservative approximation. The goal is to apply an overall degree of conservatism appropriate to the state-of-the-art, utilizing sound engineering judgment. The evidence is overwhelming that this goal can be and is being achieved.

III B.2.2 DISCUSSION OF HYPOTHETICAL CORE DISRUPTIVE ACCIDENTS

The following remarks were presented by W. H. Hannum, Assistant Director for Reactor Safety, Division of Reactor Research and Development, to the ACRS-HCDA Working Group on March 14, 1975, and were included as part of the public record of the May 27-28, 1975 Public Hearing on the PFES.

It is not my intent today to go into the question as to whether hypothetical core disruptive accidents can occur. I believe the Committee should, before it completes its deliberations, speak directly to that issue, and I can assure you that there are a variety of people, particularly from the vendor side, who are quite anxious that you should specifically consider the question of whether core disruption is a credible accident or not. I do not intend to speak to that this morning. Whether a core disruptive accident is considered to be a class 8 or a class 9 event, we must have a means for assessing the phenomena involved with it. Whether it is judged to be class 8 or 9 only affects the judgment as to whether or not it is worth doing anything about such events. Therefore, the VENUS* and PAD* type of representation must be considered, and will, under any circumstances, remain as part of the development program.

Rather, the particular question that I would like to bring to the Committee's attention is whether such a core disruption, should it occur, would be characterized by _no_ damaging energy release. If that contention can be proven, then the conclusion of your study as to what core disassembly accidents should be considered can in no way be properly characterized in terms of energy releases. We believe this contention can be generally demonstrated (with only identifiable exceptions) for LMFBR's of arbitrarily large sizes. Basically, then the sense in which I come to you today is to try and encourage you to consider that a vote on "how big is big" may be improper.

Another way we can make the distinction that I wish to raise here is that between an explosive type event and one which simply involves a fuel melting.

We can speak of core disruptive accidents, starting from very simple considerations. If we have any reactor system in which, for some reason or other, there is no control available, and we ask the question: How are we going to shut the core down, the answer is very clear. It is going to be by removal of fuel. Now, removal of fuel can either be benign, such as a fuel melting or sweepout or some such, or it could be energetic; an explosion type. It is our expectation today that we will be able to show that the "explosion" can never be an energetic explosion but, at most, a pressurization.

*VENUS and PAD are computer analysis codes. (See Section III B.1.2)

I would like to make one other general comment in introduction, and that is that we do have to be careful when we look at questions such as the function of VENUS and PAD as to what the question is that this particular segment of the methodology adresses, and what the significant output of the methodology is. What we are speaking to in this area is the manner in which a core disperses, and we are making the assumption at this point that there will be a dispersal, and that we do have to address the question of how will fuel be removed from a core in an accident situation. The output of this has traditionally been characterized by an energy. To the extent that the contention of the day is correct, the relevant output of this type of calculation may be much more in terms of defining what the products of such an event might be as they represent input to a radiological source term. Again, I will return to that point in a moment, keeping in mind the need to speak to what the question is and what the output is.

We're talking about a core disruption here, and we are going to assume that we are talking about a whole core accident. Before concluding my introductory remarks, I would like to come back very briefly to the question as to whether the whole core assumption is a valid one. Historically, the course of hypothetical accidents, design basis limiting accidents for fast reactors, starts some twenty years ago with the Bethe-Tait accidents in which, as you know, we assumed that the reactor core became dry, intact, and the clad is removed. Then, with the core operating at full power we let it slump under gravity. A number of reactor structures and containment were built with the assumption that it was prudent to contain explosive energy release that would follow from that. As we became a bit more mechanistic about the description of what happens in this area, it was decided that this was unrealistic. The Bethe-Tait accident was never really done away with; it just sort of went away. Next, we turned our attention to what happened if we got the maximum positive sodium void. And it turns out if you remove the sodium from precisely the positive reactivity zones instantaneously you can calculate an exciting enough explosion that we do not need to look to the Bethe-Tait type postulation. In the past several years, that one has gone away on a somewhat more technical basis, in that if we look at the thermal hydraulics and the voiding patterns that can occur in a core, there seems to be little reason to conjecture that the maximum positive sodium void can in any realizeable sense occur. Now, again I will come back to that one. When that one went away, the design basis trended toward what would happen if somehow or other this reactor went on a one-millisecond period and the fuel was fragmented and dispersed in the sodium. With a rapid heat transfer, from molten fuel to sodium, this would generate a strong enough working pressure to disassemble the core. Unfortunately, some people did some experiements in that area and showed that heat transfer is not that rapid, so that one went away. More recently, then, we have come back almost to the Bethe-Tait type of accident, where in a loss-of-flow scenario, the core is voided by boiling. Half or three-quarters of the core melts down, and forms a nice, dense pool in the bottom. The bloody stumps fall from above, accelerating under gravity, hitting the dense pool just at the time of prompt critical. This, again, permits us to get back into the $100 a second type ramp rate which, again, gives us a reasonable amount of excitement. Unfortunately, there are some problems with that as a contention, in that it is now proposed (principally by Jackson, Stevenson, and Fauske) that this dense pool which is postulated to collect at the bottom may be physically unrealizeable. Such a collection of molten oxide is expected to boil up and fill the available space so there is no room for these bloody stumps to drop into. There are also the postulations of means of accelerating these bloody stumps by a rapid vaporization of sodium above the core. But, experimentally, again that does not occur. In each of these instances we find ourselves looking for a mechanism whereby we can, in some physically achievable sense, accelerate materials together in a very rapid time frame. In each instance in which we try this, we find that nature does not permit such assembling.

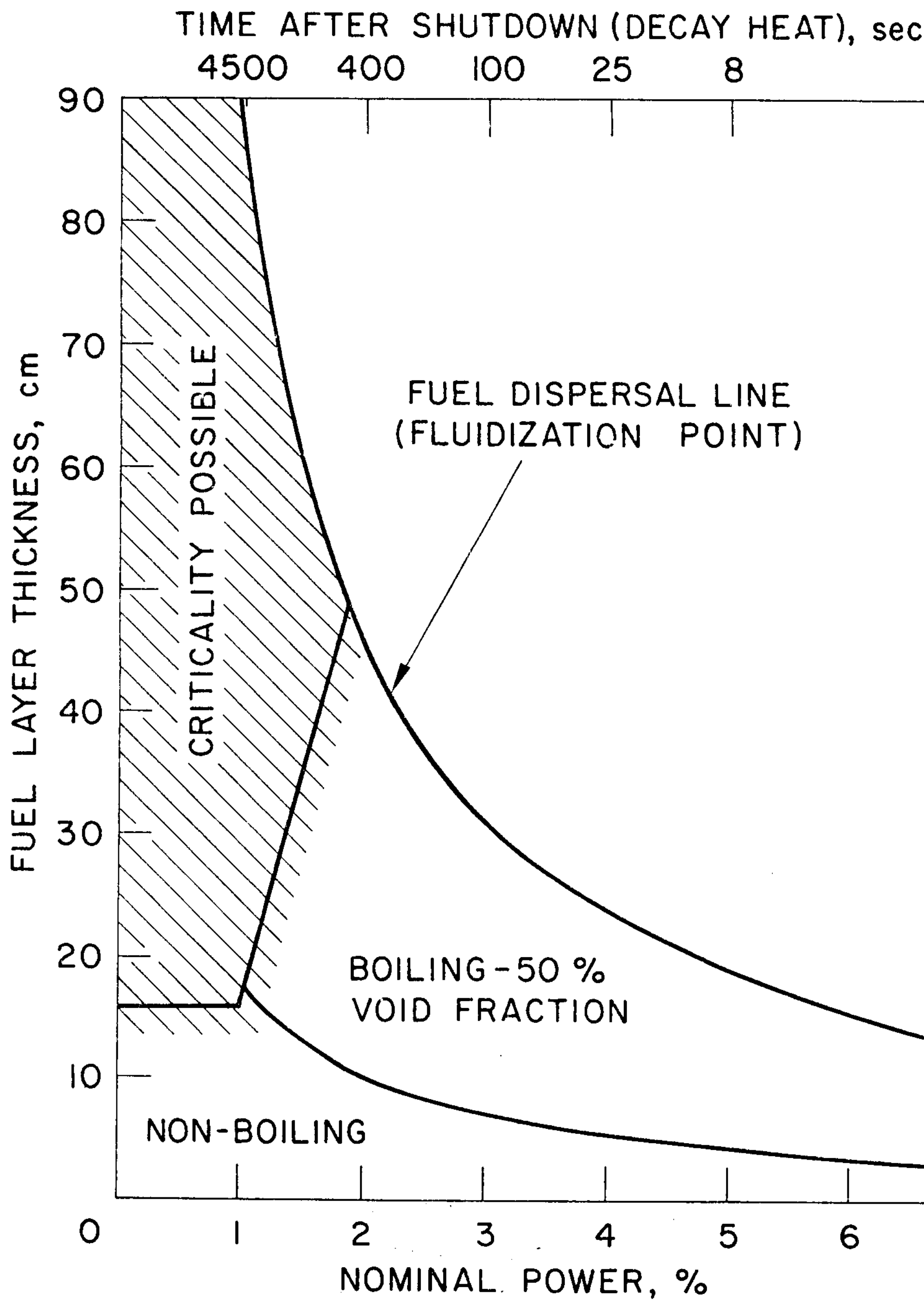
What we are faced with here is the potential for changing a twenty-year precedent. For twenty years we have looked for and found ways in which an LMFBR might undergo an energetic dispersal. I am suggesting to you today, for your consideration, that we may have come to about the end of that road of searching for ways to get an energetic dispersal.

The one exception which I promised to come back to is on the question of sodium void. As LMFBR's get larger, the positive component of the sodium void effect will grow, both in magnitude and in extent. It is, therefore, quite reasonable to expect that large LMFBR's can be designed with the potential for inserting large amounts of positive reactivity very rapidly from a sodium voiding. I would suggest for your consideration that we can stipulate that as part of the design and review process the designer be required to speak very directly to that question, and to give adequate assurance to appropriate licensing authorities that there is no way that that particular effect can lead to a public hazard. You can design a reactor so that it does not have this large positive void coefficient. But, this requires explicit design tradeoffs.

Other than from the sodium void effect, an energetic excursion requires the rapid compaction of an LMFBR core. The compaction rate must be such as to insert something in the order of \$100 per second. I prefer to speak not of \$100 per second, but to speak of a dollar in 10 milliseconds (which, of course, is the same rate). A dollar of reactivity generated by moving material in a very compact core is not easy to come by, and 10 milliseconds is not a long time. The portions involved in this would have to be either quite large, or there would have to be a substantial space available for gravity or other forms of acceleration. The velocity of motions of pieces coming together here is measured in centimeters per millisecond. These are rather high velocities, and they are hard to come by. Now, if we couple that with the boil-up, we feel we are very close at this point to being able to say that there is no way to insert this kind of reactivity into an LMFBR.

Now, let's talk for just a moment about the boil-up phenomenon. If we look to bring these materials together rapidly with high velocities, we're going to have to start by separating them. The traditional approach is to melt the oxide, collect it in a pool, formed by plugging the bottom, letting the material fall onto the plug. But, some very simple considerations suggest that the concept of a dense pool of molten oxide sitting in, and probably containing stainless steel, is unrealizeable. The boiling point of steel is at a lower temperature than the melting point of the oxide; therefore, this mixture apparently will necessarily be a froth. We can go beyond that. A recent curve of Fauske's (Figure III B-4) notes that even without consideration of the steel, if you have any serious decay power and any significant thickness, the fuel itself will boil and disperse. And if you get into the very cold fuel, down to less than a percent of nominal power, the slow criticalities that would occur there would provide enough power to boil the fuel and disperse it. It does not look like it is very serious to consider a meltdown of a very large fraction of the core when there is no decay power to melt it, in that the only thing that is going to melt the fuel in the first place is decay power. If you get into the window where there is enough power to melt it, and not enough to cause it to boil, then at this point it looks like the slow criticalities that would occur as the stuff starts to come together would itself generate enough power to boil the fuel and disperse it.

Now, another consideration that Dr. Fauske has noted is that in any such boiling as this, you would rapidly get from the dense material you start with to a bubbly flow with the volumes you have. The boiling would start to go in channels, but would almost immediately go into a fully dispersed and fluidized regime. Again, this is probably true whether we are talking about fuel vapor as the boil-up medium, or whether we are talking about some of the contained materials, such as stainless steel or some of the volatile fission products. The expectation is that the



FUEL LAYER THICKNESS VS. DECAY POWER

Figure III B-4

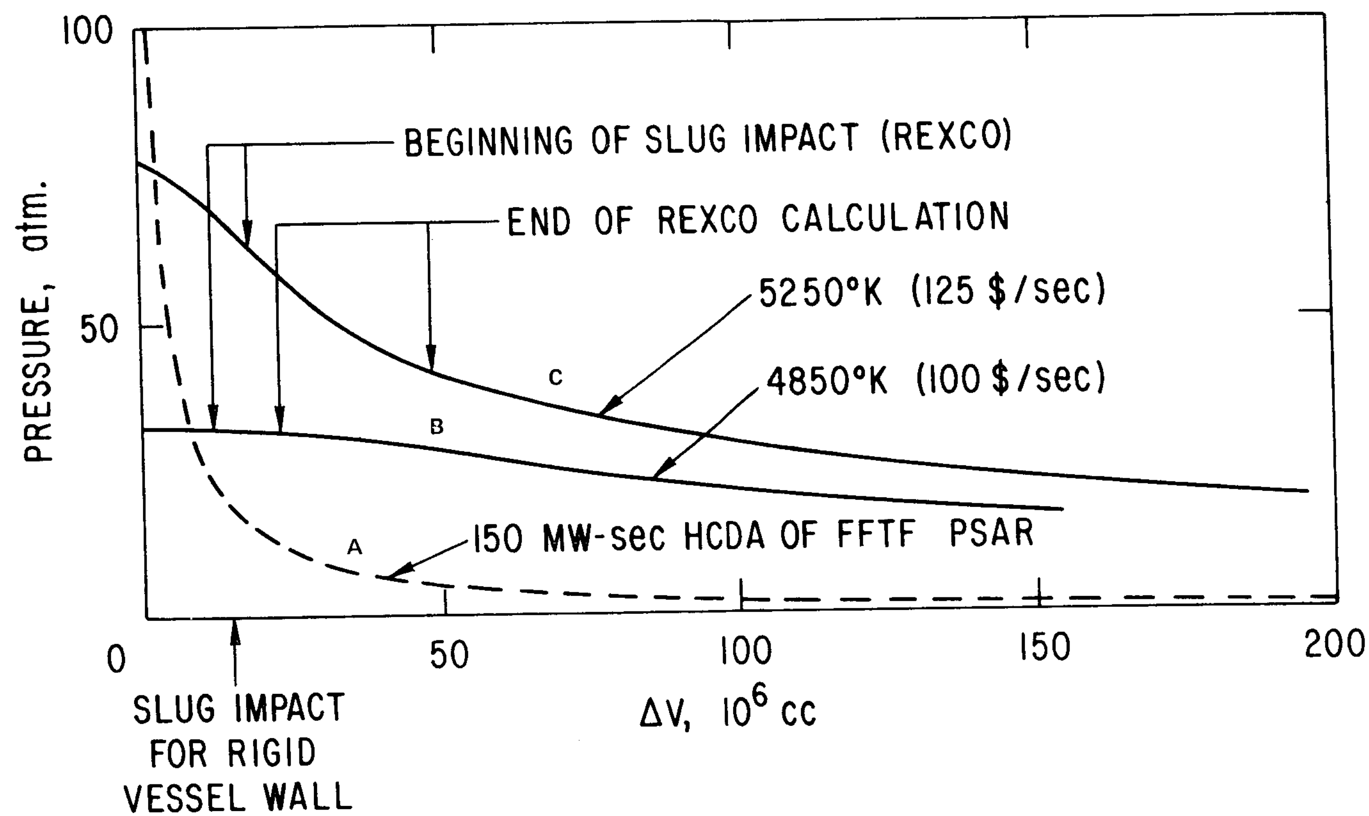
material would boil up and fill and pressurize a contained space. As you continue to generate heat, the heat has to be represented in terms of additional vaporization of at least fuel, but more likely, steel, causing a pressurization. And there does not seem to be a particular likelihood that that pressurization would remain long enough for there to be a physical settling of the particles within the mixture. If you start collecting a dense pool on the bottom, even from settling, and it gets more than, say, ten centimeters thick, it again is going to boil internally and disperse itself.

Where we stand at this point is that we are not yet ready to be so bold as to change the basic design approach for LMFBR's yet. Our approach to completing this effort, by the way, is to prove "impossible," not to prove "never." This is not a probabilistic type proof; it is a phenomenological type proof that energetic recriticalities cannot happen in realizeable situations. We do not propose to rest this argument on an "unlikely" argument, but on a "physical impossibility" argument. In order to get to the point where we would be prepared to suggest substantial change in design approach we do want to see confirmatory experiments, and we also want to have the critical public search and review to identify problems to be sure that there are not some minor secondary effects that are overlooked. ERDA is about to go into a series of large plant studies, hopefully leading to the construction of near-commercial plants of something like a thousand megawatt size. The Subcommittee's advice in the near term as to whether or not these large plant studies should consider the possibility that the energetics have gone away would be most useful.

Let me note also that the question we are speaking of here goes beyond just the question of energetics. Energetics represent a systems challenge. But energetics represent not only a requirement on the design of structures and internals. It also turns out to be one of the key determining factors as to what is the relevant radiological source term that we must speak to when considering serious accidents. Let me note two things with regard to that. First is with regard to plutonium. If plutonium is to be a public hazard, it must be in persistent aerosol size escaping from containment. (There are essentially no soluble sources from a fast reactor.) The current dominant potential source for a plutonium aerosol is from condensation of fuel vapor. Now, if in fact what we are alluding to today happens to be true, that there are no energetic dispersals, then there will be very little fuel vapor--possibly even none--which can reach the boundaries of the reactor system. If there are no plutonium vapors, there can be no condensation of that vapor in a free space so as to form a persistent aerosol. And our plutonium problem may be dramatically reduced. Further, the transport mechanism for fission products and plutonium through the deep sodium pool is by means of a vapor bubble. Again, if we do not have dramatical energetic excursions, our vapor bubble, our transporter of hazardous material to the boundary of primary system, is much less efficient, and the potential radiological source term would be substantially reduced. Thus, doing away with energetics will not only change the mechanical design, but will dramatically alter our radiological considerations.

Let me note one other factor, essentially as an aside, with regard to energetics. That is with regard to units. If we are speaking of energetics, we used to speak in terms of pounds of HE equivalent. We now speak in terms of megawatt seconds of work potential. But what any accident represents in terms of work potential depends dramatically on the working fluid. Just to illustrate the type of problem we have, FFTF structures were designed assuming that sodium was the working fluid, and that heat transfer was the means of fuel-coolant interaction. The plant was, therefore, designed to a 150 megawatt second accident, which represents Curve A of Figure III B-5. This is a very steep and very damaging pressure curve. We now believe that that type of energy transfer does not occur, but that in fact the energy transfer would be much slower. Much of the working fluid, if we did have an energetic excursion, would be fuel vapor, with sodium entrainment. Curves B and C of Figure III B-5 are characteristic of the pressure curve that would occur. The curves integrate out into the range of many hundreds to a thousand megawatt seconds of work energy. And yet, in fact, they represent less damage potential than the 150 megawatt second Curve A. As a minimum should the Committee decide to determine by vote "how big is big," I would caution you to be careful of your units, because a vote for 500 megawatt seconds may represent less of a challenge to the mechanical designer than a vote of 150 megawatt seconds, if you are talking about different working fluids.

Let me come back to the question as to whether this phenomenon, the boil-up, might actually occur on a subassembly scale as well as on a whole-core scale. Our suspicion is that the answer to that question is yes. Unfortunately, at this point I am not aware of a modeling capability adequate to provide a reasonable assessment beyond a suspicion that that is true, and we also do not have the facilities to do the experiments to either conform or illustrate the point. It is our suspicion that ultimately we will be able to show that the assumption that I made when I began, that we are talking of a whole core involvement, is in and of itself an irrational assumption. Again, the potential impact on design of that would be traumatic, but there is no experimental evidence to date. The question of plugging



PRESSURE-VOLUME RELATIONSHIPS
FOR DISASSEMBLY FUEL TEMPERATURES

Figure III B-5

precludes a very strong movement in that direction at this point. We will defer that for the next time such a Subcommittee as this is instituted. We will come back to you in five years and speak on that question. With current design, the subassembly can wall seems to be a good structural member. If we can satisfy ourselves that we understand what the force fields are in a subassembly, that could lead the designers to very different types of designs to take advantage of this one way or the other.

Just for a moment, let us consider what will be the significance when we are sufficiently satisfied of this phenomemon to take action on it. The concept of the horrendously thick steel forging that we use as a head becomes irrelevant. We can go to simple seals. The concept of very heavy walled internal structures can be dispensed with and much more efficient design of internals can be considered. The concept of relatively thick-walled vessels may give way to thinner vessels, compound vessels, or other types of approaches. A great deal of the very heavy structures may be dispensed with, allowing greater access, allowing greater design flexibility, allowing greater inspectability, allowing greater reliability, efficiency, and certainly substantially reduced costs. Those are all positive.

We must not overlook the fact that unless we accept the contention that core disruption is incredible, this or any other type of dispersal mechanism in which we involve the bulk of the core puts a very high priority on our ability to deal with debris. It introduces a great many new potentials for dispersal. And, so we have to be much more thorough and careful in our review as to how we remove heat following an accident. Thus, I do not think we have quite worked ourselves out of a job by accepting this contention.

I would also note that at this stage, and perhaps throughout the consideration of this, we feel that a fully mechanistic description of this type of phenomenon is not forthcoming. First of all, we are making an immediate jump from the SAS type representation, where we are representing an intact core, by assumptions, to a whole-core involvement. We expect that this will ultimately be shown to be wrong. The attempt to properly and mechanistically follow through a sequence which is wrong does not appear to be a fruitful venture.

I would note with regard to the potential long-term significance of this that I consider nothing to be more destructive of rational design than to insist on conservative criteria relative to something that will not happen. I can attempt to illustrate what I mean by a few examples where technology has temporarily foundered on irrelevant critiera. One example is the stiff wing of the airplane. Airplane design was held up for many years by the recognition that you are not going to let the wing of the airplane flap. When we finally decided that letting them flap was a good idea, planes immediately became much more reliable, with much more higher performance. One that goes back a bit further is the matter of solid tires. For quite a few years the concept of anything other than a solid tire was considered totally irresponsible. Single-function electronics held up the electronics field for quite awhile until the multiple-function component came about. And, of course, we are all aware of the need for a rocket casing to be self-standing. We foundered in the rocket race for many years by insisting that a rocket casing stand under its own weight. The need for straight razors to last for years led to many bloody faces before Mr. Gillette came along. And we are still struggling with the question as to whether it is responsible to design into the inelastic materials regime.

In conclusion, then, we earnestly solicit your advice relative to the HCDA with regard to what should be a design basis accident. Many people in the Clinch River project will advise you that the proper design basis accident is no HCDA. Our current technological experts advise us that the proper design basis accident is one that is in no wise characterized by damaging energy. The current guidance we have from the regulatory authorities is that we ought to consider something which is a pretty good-sized bang, and still meet 10 CFR 100. And there are even some who continue to suggest that the proper design basis accident is that which is as big as we can take without impacting the design. (I trust you will not come to that last recommendation.)

Coming back to the topic of today's meeting, VENUS and PAD, we will, of course, continue our emphasis in this area. Our emphasis in this area and our encouragement to the parallel SIMMER* effort will continue because we feel that it is very necessary that we understand the phenomena that will be involved in core dispersal. These codes will fill the role, in one way or another, of leading us to an understanding of the key phenomena. They will also be required to define what it is we are speaking of in terms of a source term. Currently, in our design efforts, we are continuing to address the question of energetics as a fallback to cover our ignorance. I hope in the near future that much of that ignorance will be removed. As to what should be a design basis accident, I would not suggest that we could rigorously define this today, but we do need to be careful when we select it that we do not select artificial and improper criteria.

*SIMMER is a computer analysis code now under development.

III B.3 ADDITIONAL INFORMATION ON THE BASIS FOR PROCEEDING WITH THE DESIGN, LICENSING, AND OPERATION OF LMFBRS WHILE THE LMFBR SAFETY PROGRAM PROGRESSES

As discussed in other supplemental material provided, there is a basis for proceeding with the design, licensing and operation of LMFBRs in advance of the completion of the R&D program. While the accumulated information in nuclear technology, as in any other body of knowledge, is not without gaps and uncertainties in the accuracy of data, there are many options available in design, engineering and operation of nuclear plants to compensate for uncertainties and to reduce associated risks to acceptable low values. Redundancy in components and instruments, conservative engineering practices providing substantial margins, safety devices and systems, fission product barriers, and a wide range of choices in operating parameters can all be used to produce safe and reliable plants. Similar options in engineering and operational practices are available to resolve additional questions that may arise during construction and testing and over the operating life of a nuclear facility.

The existence of areas in which knowledge is incomplete does not imply that appropriate criteria and evaluation models cannot be established for evaluating safety adequacy. Safety evaluations can be performed using calculations that characterize the expected behavior, together with margins based on conservative assumptions where knowledge is incomplete. This procedure establishes reasonable bounds on phenomena under consideration or otherwise provides an adequately conservative approximation. The goal is to apply an overall degree of conservatism appropriate to the state-of-the-art, utilizing sound engineering judgment. The evidence is overwhelming that this goal can be and is being achieved.

The specific current example of this is embodied in the approach being taken on the CRBR Project. The following information describes this approach.

A basic premise of the CRBR design is the conviction that a critically evaluated functional design is the controlling factor in attaining the high level of safety desired in the CRBR. The safety of CRBR is assured by a natural "three levels of design" approach. Very briefly, the three levels are 1) quality of design, 2) protection against the consequence of malfunctions, and 3) design features to protect against extremely unlikely faults. The three levels are further described below:

The first level focuses on the reliability of operation and prevention of accidents through the intrinsic features of the design, construction, and operation of the plant, including quality assurance, redundancy, testability, inspectability, maintainability, and failsafe features of the components and systems of the entire plant.

The second level focuses on the protection against "Anticipated Faults" and "Unlikely Faults" which might occur despite the care taken in design, construction, and operation of the plant set forth in level one above. This protection will ensure that the plant is placed in a safe condition following one of these faults.

The third level focuses primarily on the determination of events to be classified as "Extremely Unlikely Faults" and their inclusion in the design basis. These faults are of low probability and no such events are expected to occur during the plant lifetime. Even though they represent extreme and unlikely cases of failures, they will be analyzed using nominal calculations and sensitivity studies to establish conservative design bases. In addition, level three includes consideration of severe accidents which are even less probable than "Extremely Unlikely Faults."

FIRST LEVEL OF DESIGN

An important safety consideration in any reactor is the ability to remove heat from the fuel sufficiently rapidly that the fuel elements do not overheat during any operating or accident conditions. From this point of view, sodium is an excellent coolant because its favorable combination of viscosity, conductivity, vapor pressure and specific heat provide an excellent intrinsic capability to remove heat. In addition, a sodium-cooled reactor such as the CRBR operates hundreds of degrees below the boiling point of the coolant. Therefore, the reactor and plant need not be pressurized, the sodium surface above the reactor is at essentially ambient pressure and the pressure exerted on the coolant system boundaries of the plant is only that of the pump head required to force coolant through the reactor. For these reasons, the sodium-cooled reactor has very little stored thermodynamic energy, an outstanding advantage compared with high pressure systems, for maintaining system integrity. Small leaks, should they occur, have little likelihood of propagation into larger ones.

Moreover, the low stored energy in the primary heat transport system does not of itself generate pressure within the secondary containment structure in case of leakage, greatly reducing containment structural requirements relative to those required for light water reactor plants.

A number of conceptual and preliminary plant design decisions were made to incorporate design features which by their very nature avoid the occurrence of accidents or mitigate accident effects should they occur. Examples of these features are:

- Reactor fuel subassemblies with fuel pin spacing designed to reduce potential for reductions in coolant flow due to fuel swelling or particulate buildup on the fuel itself.
- Coordinated mechanical design of core assembly, core support and fuel handling machine control system to assure that a subassembly cannot be positioned by the fuel handling machine in a location of increased reactivity or of reduced flow (relative to design values for the subassembly.)
- A reactor vessel inlet plenum which provides multiple inlet passages and also prevents passage of foreign material greater than a certain dimension to prevent flow blockage.
- A core restraint system to control core position and assure that no positive power coefficient can be introduced by core movement.
- A device in each control rod drive mechanism to prevent any rapid outward motion of rods.
- Provisions to prevent gas from entering the reactor core, including: vortex suppressor to prevent gas entrainment at the reactor vessel and continuous bleeding of small bubbles from the system.
- A thermal liner in the reactor vessel to maintain the upper vessel walls 100-150°F cooler than the reactor outlet temperature and protect them from thermal transients associated with power level changes.
- A negative Doppler coefficient of reactivity, to provide a reliable feedback mechanism enhancing stability in normal operation and limiting reactivity excursions.

SECOND LEVEL OF DESIGN

Recognizing that errors, or malfunctions can occur despite the care and attention given to the plant design, construction, operation and maintenance, two avenues of second level pursuit have been followed: (1) a number of protective systems and plant features have been provided to protect against malfunctions, and to limit their consequences to definable and acceptable levels, and (2) a program of development and testing has been undertaken to define clearly the nature and consequences of accidents, such as fuel failure, which might result from malfunctions. These features are:

- The plant protection system provides prompt automatic shutdown of the reactor when necessary to correct for off-normal conditions in the system. Two redundant, independent systems are provided, each system is complete with diverse sensors, logic, and circuitry, and each actuates separate sets of neutron absorber rods.
- All systems, components and structures required for continued safe operation are designed to withstand or be protected from the effects of abnormal environmental conditions such as earthquakes of floods.
- The three-loop design provides a redundant heat removal system such that core cooling is maintained even if, at the same time as a loss of normal power, an active component of one loop is disabled.
- Pony motors are provided as a backup to natural circulation for the primary and intermediate loop pumps of the heat transport system. They operate automatically upon reactor scram or shutdown to provide forced coolant circulation with or without off site power.
- Extensive sodium leak detection capability is provided to assure that any failure of the primary boundary is detected promptly so that corrective action can be taken.
- The primary system components of each of the three independent heat transfer systems is installed in an isolable massive reinforced concrete, steel lined, inerted cell.
- A sensitive and redundant system detects the initiation of small leaks in the steam generator modules.
- A steam generator protection system handles reaction products in the event of a large leak.
- Guard vessels and elevated piping assure core coverage and continuity of core cooling even in the event of primary coolant system leaks.
- Steel lined vault construction and cooling provisions are similar to FFTF.
- A natural circulation capability in the heat transport systems enhances removal of decay heat.

<u>Supporting Development Activities</u>

The second level of design is supported by a broadly based testing program in support of design for normal plant operation, supplemented by developmental data gained for FFTF and other reactor experience.

Typical of the development programs is that required to establish the adequacy of the design of the secondary control rod system for the CRBRP, needed because this represents a design that has been deliberately selected as being diverse from the primary control system. The secondary control rod system development program includes tests of the following:

- Control rod release latch mechanism.
- Control rod deceleration device.
- Control rod position indicator.
- Latch seal to the control assembly.
- Control assembly (flow tests).
- Prototype units.

A large-scale reliability program has been drawn up, and will be vigorously pursued. The plan provides for:

- Procedural reliability requirements placed on plant components and systems.
- Failure modes and effects analyses of all safety related plant systems and components.
- Fault tree analysis to establish the critical combinations of failures.
- Quantitative reliability analyses, based on the fault trees and other methods.
- An extensive program of reliability testing to establish a comprehensive bank of reliability data.
- Proof testing of components and systems prototypic of the design.

THIRD LEVEL OF DESIGN

At the third level of design, emphasis is placed on provision of protection against faults of extremely low probability (designated as Extremely Unlikely Faults). No events in this category are expected to occur during the plant lifetime. Nevertheless, provision has been made to assure public protection against even these events.

Typical of the features included to provide protection at this level are:

- A low leakage containment building having a 10 psi internal pressure capability, although the maximum calculated pressure from any analyzed accident is substantially less than 10 psi.
- A containment isolation function within the plant protection system, to assure rapid isolation of the containment building in the event of a radiological release.
- An auxiliary decay heat removal system.
- All systems, components and structures required for safe shutdown designed to withstand or be protected from the effects of Extremly Unlikely Environmental

Conditions, such as severe earthquakes, maximum flood level, severe forest fires, and tornadoes.

In addition to the safety features provided in the above levels, increased margins are included in the design to provide additional protection against unforeseen events. Specific examples of safety features associated with these margins are:

- Impulse energy absorption features in the reactor head.
- Primary system features (including supports) designed to accommodate above normal dynamic loadings.
- Reactor core internals designed to enhance post accident cooling capability and reduce the potential for secondary criticality.

Finally, in addition to all the above, a parallel design effort is being conducted which will incorporate core disruptive events within the design basis. These events are believed to be so low in probability that it is inappropriate to include them within the design basis spectrum. However, some of the data to conclusively demonstrate this low probability is still being developed. Examples of specific features being considered for providing additional protection against these events are a device which would retain and cool the debris resulting from the accident and a sealed, inerted compartment above the reactor.

III B.4 ADDITIONAL INFORMATION ON LMFBR RISK ASSESSMENTS METHODS DEVELOPMENT

The following data represents ERDA staff responses to questions posed by the Internal Review Board at the May 27-28 Public Hearing on the PFES and were included as part of the record of that hearing.

1. What is the nature of the R&D effort?

   Efforts are underway in RRD to explore the application of logical methods in risk assessment of LMFBRs. We believe that the application of systems of logic to the subjective area of safety decision making can be useful and intend to exploit these techniques to the extent they can be solidly justified. Our approach is cautiously optimistic with regard to the expected benefits to be gained from these approaches. At this time, the work is investigatory and exploratory in nature, since we are not yet satisfied that the benefits will be proportional to the necessary cost of the program. Our objective is to have in hand by the mid 1980's a credible, accepted method of quantitative risk assessment for LMFBRs and a sound evaluation of the level of confidence which can be placed on such assessments.

   There are uncertainties in risk analysis which can be large. This program must determine the magnitude of the uncertainties to aid RRD in future safety decision making. Sources of uncertainty include the limited amount of operating data on LMFBR components, lack of any data from commercial plants, and lack of sufficient detailed knowledge on in-core phenomena.

   The major portion of the current base program referred to here is carried out by General Electric with a smaller involvement in the area of basic methodology improvement by LASL and ANC. Additional related studies are undertaken by reactor vendors. The overall approach in the base program is to identify special needs and special problems which impede the conduct of risk assessments for LMFBRs, develop special risk assessment methodologies, where necessary, test these methodologies on early LMFBRs (FFTF and CRBR) and prepare and publish such developed and tested procedures for general use. Anticipated outputs of such a long term effort will be relative ranking of various components and systems with respect to contribution to overall plant risk, identification of data needs, establishment of priorities for R&D needs, and LMFBR risk assessment procedures.

2. What is the timing of such R&D? What is the likely impact on design?

This program is scheduled to produce quantitative risk assessment methods available for use in 1985. Prior to the accomplishment of this program objective, there will be outputs available as described above. As an example of specific outputs, there will be a definition of R&D needs as defined by analysis of three FFTF events, an assessment of R&D needs as defined for an early LMFBR, and a comparison of the relative risk reduction potential for various combinations of early LMFBR systems and design variations of such systems.

LMFBR probabilistic risk assessment is expected to verify and quantify our belief in the safety of LMFBRs; it could provide a basis for less redundancy in design in some areas and it should indicate needed adjustments in emphasis in the R&D areas.

3. What is the interim solution pending completion?

At the present time, the approach to LMFBR safety is that which has been used for LWRs. The safety of LWRs was achieved through use of safety R&D results sponsored by both government and industry, the Regulatory review process, and the employment of conservative engineering practice. The LMFBR will be made safe by the same processes. This is our primary approach at the present time. If the methods now being explored indeed prove to be as useful as we hope, we would anticipate an increasing degree of acceptance, which however will be gradual and evolutionary.

In summary, the present safety approach is to take advantage of the inherent safety features of the LMFBR, to utilize conservative design practices and to use probabilistic risk assessments whenever these appear to be advantageous.

SECTION III C

SAFEGUARDS PROGRAM INFORMATION

INTRODUCTION

The material provided in Section III C is in response to the request in the "Report to the Administrator on the Proposed Final Environmental Statement for the Liquid Metal Fast Breeder Reactor Program by the Internal Review Board (June 20, 1975)," (see Section IV B) which was adopted by the Administrator (see Section IV A), that "the final statement should describe the minimization concepts listed in the PFES and assess the extent to which each of these can reduce the safeguards risk" and that the final statement "should discuss the sequence of steps, the timing, the problem definition and the methodology of the various ongoing studies and programs which are relevant to the environmental and economic acceptability of an LMFBR industry."

The adequacy of current regulatory safeguards standards is reviewed in Section 7.4.7 of the PFES. Licensing activities, physical protection and material control and accountability for fixed facilities, transportation safeguards, and inspection, enforcement, and response are each addressed in significant detail. Past reviews and criticisms of safeguards adequacy are presented and responded to in detail in PFES Volume IV, Appendix IV A. It is recognized that the absence heretofore of malevolent acts involving special nuclear materials and facilities handling these materials does not in itself unequivocally demonstrate the effectiveness of a safeguards system (i.e., such absence could be the result of the lack of criminal motivation rather than the deterrence thereof). However, the fact that malevolent acts have not occurred, even in the very substantial plutonium operations conducted by the government for the past 30 years, is corroboratory evidence of the effectiveness of the system.

Despite past and current effectiveness, it is recognized that changes will be required in safeguards in the future. This requirement for change will arise out of changes in the nature of the threat, the expected increase in the commercial utilization of strategic special nuclear material, and the widespread placement of safeguarded facilities which will inevitably involve varied geographical environments. Safeguards changes, which have been thoroughly discussed in the PFES, do not involve or require invention or research breakthroughs. They require only the logical extrapolation, refinement and application of methods already in use or partially developed. To gain an optimum future safeguards posture, the appropriate application of time, money and people is required but no research into unknown areas is involved.

The societal effect of the future safeguards measures implemented as the result of the R&D program is not likely to be disruptive. The financial costs are not expected to have significant effects on the overall LMFBR cost-benefit balance. These points are covered in Sections 5 and 7.4.9 of the PFES.

In summary, it is anticipated that the R&D program will generate safeguards adaptations at a pace consistent with the developing LMFBR requirements. The staff is firm in its previously stated conclusion that there is no safeguards-related reason to delay the further development of the LMFBR.

Additional information on safeguards research and development, and related matters, may be found in Volume 3 of the Public Hearing Record for the Public Hearing held May 27-28, 1975 on the PFES, on pages 253-387, 519-540, and 575-584. Copies of the Public Hearing Record are available for inspection at the ERDA Public Document Room at 1717 H. Street N.W., Washington, D.C. as well as at ERDA's Albuquerque Operations Office, Kirtland Air Force Base East, Albuquerque, New Mexico; Chicago Operations Office, 9500 South Cass Avenue, Argonne, Illinois; Idaho Operations Office, 550 Second Street, Idaho Falls, Idaho; Oak Ridge Oprations Office, Federal Building, Oak Ridge, Tennessee; Richland Operations Office, Federal Building, Richland, Washington; Nevada Operations Office, Las Vegas, Nevada; San Francisco Operations Office, 1333 Broadway, Oakland, California; and Savannah River Operations Office, Savannah River Plant, Aiken, South Carolina.

7.4.8.1.2S MINIMIZATION ACTIVITIES

Section 7.4.8.1.2 of the PFES lists a number of general areas where measures might be taken to reduce the consequences of a successful adversary action. Successful adversary action means: adversary has stolen material with intent to make a nuclear explosive or to disperse radioactivity; or adversary has carried out an act of sabotage with the intent to disperse radioactivity. An approach to measuring the risk reduction resulting from implementation of safeguards measures including the consequence reduction mechanisms discussed below is described in Section 7.4.8.1.3S(b). The approach is comprised of efforts addressed toward estimation of (a) frequency of attempt (threat definition), and (b) conditional probability of adversary action sequence completion (interruptive capability); and calculation of consequences.

A discussion of the consequence reduction measures under consideration is contained in the following paragraphs:

1. Facility Siting, Design and Operating Criteria

   (a) Facility Siting
   Present regulations specify that nuclear facilities are to be located to reduce to a low level the consequences of accidental release of radioactive materials. Studies are underway to determine if these criteria are also adequate in case of sabotage.

   (b) Facility Design
   Nuclear facilities are designed to contain radioactive materials in case of accident and to withstand hurricanes and tornados. These design features will be reviewed to determine whether additional design criteria might be cost effective for reducing the consequences of acts of sabotage. In addition to containment, instruments and processes should be designed to prevent accidental release of radioactivity and the possibility of criticality accidents. These and possible additional measures of a similar nature may substantially reduce the consequences of sabotage attempts.

   (c) Facility Operations
   As in the above cases, operating safety criteria also serve safeguards objectives. For example, minimizing the amount of plutonium contained

in process equipment reduces susceptibility to sabotage and limits the amount accessible for theft in a short time.

2. Transport Design and Operating Criteria

A number of regulations have been implemented for protection of nuclear materials in transit and additional measures are being studied. Such measures as armoured vehicles and massive shipping containers will reduce the consequences of sabotage attempts. Routing to avoid highly populated areas would reduce the potential injury resulting from a possible successful sabotage attempt.

3. Material Form Criteria

Both ERDA and NRC are conducting studies relating to the nature and form of plutonium bearing materials which will be employed in the plutonium recycle and breeder fuel cycles. Several of these studies concern the costs of alternative forms which might reduce the consequences if attempts were made to fabricate nuclear explosives or to cause radiological incidents. Two of these are:

(a) Addition of radiation emitting isotopes to impede fabrication of an explosive or to reduce the power of the explosion.

(b) Requiring that plutonium be shipped in chemical and physical forms which would be less toxic, if dispersed. For example, if $Pu\ O_2$ is dispersed in the air a substantial fraction of the powder inhaled would be retained in the lungs and might cause cancer if the crystal size is small. However, if the crystal diameter is 10 micrometers or larger, very little of the inhaled oxide would remain in the lungs.

4. Automatic Alteration of Materials or Facilities

Measures of this nature are being studied both to protect materials from theft or sabotage and to reduce the consequences should such acts be accomplished. A system could be designed to dilute high enriched uranium with depleted uranium within a facility or a container in transit when an emergency occurs. Plutonium could (less effectively) be diluted with the spontaneous neutron emitting isotopes of plutonium. Within a facility, it may be possible to rapidly move material from a process line to a containment that is highly resistant to criticality assembly or to dispersal. It is anticipated that more ideas will be forthcoming as these studies are pursued.

5. Evacuation and Decontamination Planning

Several years ago, the AEC set up radiological assistance teams and developed procedures for a coordinated response with other federal, state and local agencies to deal with significant nuclear accidents. The AEC has had experience with nuclear accidents and has, so far, been successful in preventing exposure of the public. Presently ERDA is cooperating with other government agencies in plans to evacuate and to decontaminate areas that might be threatened by major nuclear accidents or by deliberate anti-social use of nuclear materials. Extensive plans to protect the public in case of serious nuclear or other emergencies are set forth in Federal Statutes and executive orders. Two key agencies are the Office of Preparedness under the General Service Administration, and the Federal Disaster Assistance Administration in the Department of Housing and Urban Development. They are responsible for coordinating the ERDA radiological emergency response capabilities and the resources of other government agencies to cope with evacuation, medical attention, decontamination, relocation, and other measures as might be required.

7.4.8.1.3S ERDA FUTURE SAFEGUARDS PROGRAM

Section 7.4.8.1.3 of the PFES describes the future safeguards program in terms of a number of general interrelated activities performed by the research and development and regulatory arms of the AEC (now ERDA and NRC). Recent planning activities have resulted in an improved and more specific description of the ERDA safeguards program, which follows. For completeness, general information on NRC safeguards activities is also provided.

1. Introduction

The ERDA safeguards program includes the development of capability to make improved threat predictions and system effectiveness evaluations, and the design and demonstration of balanced, flexible safeguards systems for application to future fuel cycles. The material which follows shows that the program will permit an ERDA management decision in the early 1980's on the safeguards-related acceptability of the LMFBR for future wide commercial use, should such a decision be considered appropriate at that time.

Before describing the safeguards program for the LMFBR fuel cycle, it should be stated that the ERDA safeguards program relates to all nuclear fuel cycles. In general, the policies and techniques developed to protect nuclear material in one facility or shipment are applicable to protection of the same kind of nuclear materials in other facilities or shipments. Physical protection systems, whether for a light water reactor or an LMFBR fuel fabrication facility, employ the same elements and are based on the same principles of defense-in-depth, although the particular mix of elements will depend on the specific facility. There is little, if any, difference between the type and number of measurements needed to account for the plutonium in a facility for fabricating mixed-oxide fuel for plutonium recycle and those for an LMFBR fuel fabrication facility. Most of the safeguards measures mentioned in the PFES and in this supplement will be studied for application to existing nuclear facilities and to other new fuel cycles as well as the LMFBR. The experience which has been gained in the past and which will be gained from near-term new facilities will serve to prove the safeguards measures which would later be available for application to the commercial LMFBR.

2. Supplemental Information on the Future Safeguards Program

The following sections relate to the subtopics as presented in PFES Section 7.4.8.1.3, pages 7.4-61 through -64.

(a) Improvement of Threat Definition

A safeguards system is designed to successfully counter a set of defined threats. There is no actual experience of consummated threats against nuclear facilities or involving nuclear materials. Consequently, threat analysis must be based on an understanding of the properties of nuclear materials which an adversary might seek to exploit, and inferences as to the motivation and characteristics of possible adversaries drawn from adversary activities in other fields.

Studies currently underway at national laboratories and contractors involve identifying the motivations, resources, and other attributes of potential adversaries; identifying and ranking the ranges of credible threats; and considering the reasons why an adversary might choose a nuclear target. These and related studies are designed to provide information regarding the range of threats which might be encountered, and to provide an upper limit estimate of the likelihood that a given attempt might occur. This information defines the threats which present or future safeguards systems should be designed to counter.

Because threat definition is a continuing process which must take account of changing societal situations and advances in technology, it is not useful to attempt to identify a point in time at which threat definition for LMFBR can be terminated. However, work to be completed within the next several years should permit credible scoping of potential threats against a future LMFBR industry. As shown in Table III C-1, completion of the currently assigned tasks is scheduled for 1977, and a preliminary design basis threat definition for LMFBR is to be completed in 1978. The LMFBR safeguards system design activity, described in (d) below, will take into account the range of threats as determined at that time and the remaining uncertainties in threat prediction.

(b) Improvement of Safeguards System Design and Evaluation Capability

Safeguards system design is an iterative process: assessment of threats, assessment of the capability of existing safeguards to effectively counter the threats, and improvement of the system to remedy existing or anticipated weaknesses. A formal, analytical framework has been developed for this process and is reported in "Societal Risk Approach to Safeguards Design and Evaluation," ERDA-7, June 1975. The process consists of identification and ranking of events of concern (e.g., nuclear explosions

Table III C-1

ERDA SAFEGUARDS PROGRAM FOR LMFBR - ACTIVITIES AND MILESTONES

	CY
(a) Threat Definition	
. complete current studies	77
. start design basis definition	77
. complete design basis definition	78
. continuing review	into 80s
(b) System Design and Evaluation Capability	
. ERDA-7 published	June 75
. start application of effectiveness evaluation techniques to ERDA facilities	Fall 75
. start system design modifications	Winter 75
. complete application of effectiveness evaluation techniques to ERDA facilities	78
. complete system design modifications	78
. continuing refinement	into 80s
(c) Interruption and Consequence Reduction Capability (Generic System Demonstrations)	
. Computerized Pu accountability system at Los Alamos facility	78
. Physical protection at Sandia Test Reactor	78
. Pu storage protection system at Atlantic Richfield facility	79
. continuing activities	into 80s
(d) LMFBR System Evaluation	
. Synthesis and comprehensive evaluation of future LMFBR safeguards systems	78-82*
(ERDA management decision on safeguards-related acceptability of LMFBR for future wide commercial use possible in early 80s)	
. Start long-term demonstrations	
HPFL	82
CRBR	83
Hot Processing Plant (HPP)	late 80s

*Based upon availability of LMFBR facility design information per the following schedule:

. Clinch River Breeder Reactor (CRBR)	complete in 76
. Prototype Large Breeder Reactor (PLBR)	78-81
. High Performance Fuels Laboratory (HPFL)	complete in 78
. Hot Processing Plant (HPP) design study	77-79

or radioactivity dispersals) in terms of their potential consequences; identification of possible adversary action sequences which could lead to such events; and evaluation of the effectiveness of an existing or postulated safeguards system to provide protection.

The methodology for estimating the consequences of events of concern is already well in hand, primarily as the result of extensive ERDA (formerly AEC) experience in nuclear safety design and accident and weapons effects evaluation. Thus, work in this area consists of application of existing analytical techniques.

With respect to methodology for evaluating safeguards system effectiveness, it is considered that significant improvements will be required. Thus, high priority is being given to improving the analytical capability to assess the effectiveness of integrated safeguards systems and their subsystems against adversary actions. Several analytical methods have been developed for this purpose. These include: diversion path analysis, developed under contract with the National Bureau of Standards; "black hat" techniques, developed by Sandia Laboratory to evaluate protection systems for weapons materials; and computer-aided systems to evaluate facility protection plans, developed at the Sandia and Brookhaven Laboratories. These efforts are not dependent on Threat Definition results, but rather involve the development of methods which can be used to predict the effectiveness of any postulated safeguards system for any range of postulated threats.

The analytical methods mentioned above are now being applied to determine the strengths and weaknesses of existing safeguards systems at ERDA facilities and to assess proposed modifications and additions. In the process of application, the analytical methods themselves are being refined and improved.

As indicated in Table III C-1, the improvements in system design and evaluation capability will have been achieved by about 1978.

(c) Improvement of Capability for Adversary Action Interruption and Consequence Reduction

The PFES (pages 7.4-61, -63) briefly describes eleven measures for possible implementation in addition to the many measures presently employed to safeguard nuclear materials and facilities. These and other suggested safeguards measures are under study by NRC and ERDA at this time; the results of these studies will be available in the near future. ERDA is in the process of implementing item (c) in the PFES list: the use of specialized vehicles for transport of all ERDA-owned plutonium and high-enriched uranium. By the fall of 1976, ERDA will implement its nationwide system, which employs specialized vehicles, radio communications, and armed escort vehicles. This technology will be available for application to the commercial sector.

Some of the other ERDA development and demonstration programs which can be applied to commercial nuclear fuel cycles deserve mention:

- Portal monitors have been developed and are now commercially available which can detect a gram or less of plutonium on a person passing through. A tamper resistant portal monitor has been demonstrated. More sensitive and foolproof personnel and package monitors are under development. Sensitive portable instruments have been developed to search for nuclear materials in vehicles and other hiding places.

- A variety of non-destructive instruments have been installed and successfully tested in the existing plutonium processing facility at Los Alamos. Data from the instruments are fed to a mini-computer. This is the first step in design of an integrated system for keeping close account of the material in a plutonium processing line on an essentially continuous basis. When the new Los Alamos plutonium processing facility is completed in 1978, it will contain an automatic computerized measurement system designed to detect immediately even a small diversion from the process lines.

- The performance of physical protection components such as barriers and alarms, electronic surveillance, and automatic protective mechanisms is being evaluated at the Sandia Laboratory. Demonstrations will be conducted at Sandia's Test Reactor starting in 1978.

- Systems are being developed for highly automated operation of plutonium storage vaults for increased security and to facilitate the taking of inventories. These will be demonstrated at the Atlantic Richfield Plutonium Storage Facility in Hanford, Washington starting in 1979.

The studies, applications and demonstrations mentioned above, together with other safeguards measures in place or under evaluation at ERDA facilities, will provide an increasingly extensive and variegated inventory of technology which can be drawn upon to design safeguards systems for application to a future LMFBR commercial industry.

(d) Systems Evaluation and Recommendations for Improvements

The efforts described in the preceding paragraphs will provide the methodology and technology necessary for synthesis of feasible safeguards systems for application to the future LMFBR industry, and for realistic evaluation of the effectiveness of these systems against a range of predicted future threats. This work will reflect the threat definition activity described in (a), the evaluation techniques described in (b), and the safeguards measures in use and under development discussed in (c). The formal synthesis and evaluation process is expected to commence in 1978 or 1979; the completion date would be no sooner than 1980, and probably no later than 1982. To meet this schedule, it will be necessary that the research, development and demonstration program for the LMFBR and its fuel cycle proceed such that technical information on facility design and related matters becomes available on a timely basis. (Table III C-1 shows the present reference schedules for design of key LMFBR facilities.) It is during the 1980-1982 time period, then, that definitive safeguards-related information relevant to an ERDA decision on acceptability of future wide commercial use of the LMFBR would be provided.

The various safeguards systems which will be synthesized during this period will include many subsystems which have already been used at ERDA and/or licensed facilities. Other subsystems may not yet have been used in a commercial or near-commercial environment. The process of demonstration in LMFBR facilities (prior to actual wide commercial use of the LMFBR) can be expected to be carried out over a period of 10 years or longer, and should not be viewed as a prerequisite to an ERDA decision on LMFBR commercialization, but rather as a means to provide continuing assurance that nothing has been overlooked. Examples are: demonstration of a safeguards system for LMFBR fuel fabrication at the High Performance Fuels Laboratory (HPFL) pilot plant; demonstration of a system for protection of breeder reactors at the Clinch River Breeder Reactor; demonstration of a system for reprocessing plant protection at the proposed Hot Processing Plant (HPP) pilot facility. The first of these is described below in some detail.

The High Performance Fuels Laboratory (HPFL) will be constructed at Hanford, Washington. It is to be a pilot scale fuels facility with supporting laboratories to develop and demonstrate LMFBR fuel fabrication processes, equipment, and related technology. The HPFL will provide the technical base for development of the necessary commercial manufacturing capability for LMFBR fuels. Safeguards demonstration will be preceded by analysis of vulnerability to overt and covert access to SNM, as well as sabotage; design of countermeasures to suitably strengthen desired areas; and design of the physical security system. Safeguards design will also involve application of advanced techniques for materials control and accountability and protection of plutonium inventory, involving extensive use of on-line non-destructive assay methods, on-line inventory, and highly automated and protected process operations to minimize access to SNM. The process operations and vaults will be designed to resist diversion and will incorporate alarms, warning systems, and tamper-safing features. A systematic design of the total system, interfacing with the requirements of a highly automated, high through-put process line operation, will achieve maximum protection for a given investment. Development of design principles and criteria for this system is underway. Construction of the HPFL is scheduled to start in 1978 and the pilot line is scheduled to begin operation in 1982 at which time the safeguards system will be operating as an integral part of the facility and will be available for evaluation.

The CRBR will be subject to NRC license requirements and inspection. The safeguards for this facility should set a high standard to help assure that LMFBR commercial power plant safeguards will be highly effective.

The schedule and the site for the HPP have not yet been determined; it is postulated that this facility would commence operation in the late 1980s. Earlier demonstrations might be conducted at ERDA reprocessing plants (Idaho, Savannah River), or licensed plants under construction (Barnwell).

(e) Safeguards Policy Decision

As indicated above, the ERDA safeguards program is expected to provide, in the 1980-82 time period, definitive safeguards-related information relevant to an ERDA management decision on the acceptability of the LMFBR for future wide commercial use. As stated in the PFES (pages 7.4-63, -64), recommendations for future safeguards will take into account a cost-benefit analysis of environmental, safety, economic, social, operational, and other impacts as well as the effectiveness of the proposed measures. Using this information, an ERDA management decision on the acceptability of the LMFBR for wide commercial use, from the safeguards point of view, should be possible in the early 1980's.

(f) Promulgation of Safeguards Requirements, Operations Including Licensing Review and Inspections, and Materials and Plant Protection Operations

The Energy Reorganization Act transferred the licensing and inspection operations for privately-owned nuclear facilities from the regulatory arm of AEC to the Nuclear Regulatory Commission. Responsibility for promulgation of safeguards requirements and inspection of Government-owned nuclear facilities was transferred from the AEC to ERDA (except for new demonstration power reactors and nuclear waste disposal sites, which are subject to NRC licensing and inspection).

ERDA is charged to develop and to demonstrate the effectiveness of safeguards for new fuel cycles. NRC is to conduct confirmatory research and to determine whether the safeguards plans submitted to NRC by ERDA for facilities subject to NRC licensing, and plans submitted by private facilities, satisfy NRC criteria.

While the regulatory responsibilities of NRC and the developmental responsibilities of ERDA must be clearly separated, the activities of the two agencies toward improved safeguards will be coordinated. The national safeguards system should be balanced, which is to say that equally effective safeguards should be applied to ERDA and licensee facilities and materials. Also, the experience gained in one sector should be applicable to the other. To the extent that safeguards measures applied to ERDA facilities also apply to licensee facilities (which is usually the case), ERDA has the responsibility not only to optimize such systems but also to make safeguards system design and operating experience available to the nuclear industry and to NRC.

These considerations encompass physical protection, materials accountability and measurement, information handling, inspection strategy, information processing and all the other components of a safeguards system.

(g) U.S. Government Interagency Operations

ERDA will cooperate with NRC and with other government agencies in those aspects of nuclear safeguards which transcend individual agency responsibilities. ERDA will assist in the development of plans and procedures for deterrence, interdiction and response and recovery where nuclear materials are involved. ERDA technical capabilities will be developed and maintained as required to support inter-agency emergency preparedness plans covering nuclear sabotage, dispersal, or explosion and to support any search and recovery procedures conducted by or with other agencies. ERDA considers that it has a responsibility to insure the development and maintenance of all interagency programs that relate to safeguarding of nuclear materials.

ERDA will also continue to play a responsible role in support of the International Atomic Energy Agency and take into consideration the implications for international safeguards and IAEA inspection as it is developed for existing and new nuclear fuel cycles.

SECTION III D

RADIOLOGICAL ASSESSMENT OF CARBON-14 RELEASES FROM THE LMFBR FUEL CYCLE

AND

RADIOACTIVE WASTE MANAGEMENT

INTRODUCTION

This discussion presents supplementary material on two distinct subjects relating to Sections 4.4 and 4.6 of the Proposed Final Environmental Statement (PFES):

Section III D.1 - RADIOLOGICAL ASSESSMENT OF CARBON-14 RELEASES FROM THE LMFBR FUEL CYCLE, and Section III D.2 - RADIOACTIVE WASTE MANAGEMENT.

Section III D.1 deals with a subject which was not fully treated in the PFES because its significance as a radiologic hazard in the LMFBR fuel cycle was not fully appreciated at the time the PFES was prepared. Figure III D-1 provides an index of the material covered in this section.

Section III D.2 discusses two aspects of radioactive waste management which require further amplification. Item A provides an updating of the situation with respect to migration of radioactivity from low-level burial grounds since the PFES was prepared. Item B presents the preliminary Radioactive Waste Management Plan as of September 1975. Figure III D-2 provides an index of the material covered in this section.

INDEX OF SECTION III D.1

Figure III D-1

INDEX OF SECTION III D.2

Figure III D-2

4.4S RADIOLOGICAL ASSESSMENT OF CARBON-14 RELEASES FROM THE LMFBR FUEL CYCLE

1. INTRODUCTION

This section provides supplementary information in response to comments noting that the Proposed Final Environmental Statement (PFES) for the Liquid Metal Fast Breeder Reactor Program does not include an analysis of the consequences of production and release of Carbon-14 during operation of the LMFBR* fuel cycle.

Carbon-14 is a beta emitting radionuclide with a half life of 5,730 years. In nature, it is produced by cosmic rays in the upper atmosphere and then enters the biosphere through photosynthesis. Carbon-14 has been extensively studied for many years since it provides a means to investigate the dynamics of the carbon cycle and to date the time of death of organisms. Knowledge from this work provides a substantial basis for estimating the radiation dose to man resulting from Carbon-14 in the environment.

Carbon-14 (^{14}C or C-14) was not thoroughly treated in the PFES because the magnitude of the radiological hazard constituted by its presence in spent LWR and LMFBR fuels was not at that time recognized either generally or by those who prepared the report. Carbon-14 had been recognized earlier as a product of atmospheric nuclear tests,[1] as a problem in stimulation of gas release via nuclear explosions,[2] and as a concern in reprocessing of fuels containing large quantities of carbon,[3,4] as is the case with Rover and HTGR fuels.**

This supplemental information provides an appraisal which is as accurate as the available information permits. The uncertainties are identified and are expected to have little effect on the magnitude of the indicated results.

2. SUMMARY AND CONCLUSIONS

The rate of production of Carbon-14 in the LMFBR fuel cycle is estimated to be approximately 10 Ci/GWe-year* (see 3). The total rate of release of C-14 from all LMFBR fuel cycle facilities is estimated to be 0.1 Ci/GWe-year or less (see 4). According to this estimate, less than 0.003 MCi of C-14 would be released as a result of the projected generation of 22,700 GWe-years of electrical energy by U.S. LMFBR's through the year 2020 (See PFES, Table 9.1-15.) This amount of C-14 is small compared to the global inventory of natural C-14 (280 MCi) and the amount of C-14 produced in atmospheric weapons tests (6 MCi).

*See List of Abbreviations in Volume I of the PFES.
**See also page 6A.1-96 of the PFES.

For a projected annual generation of 1,650 GWe-year by U.S. LMFBR's in 2020 (PFES Table 9.1-15) the rate of release of C-14 (less than 200 Ci/yr) is a small fraction of the rate of production of natural C-14 (30,000 Ci/yr).

The population dose to a constant world population of 6 x 10^9 over the entire lifetime of C-14 in the environment is approximately 260 man rem/Ci released. The production of 22,700 GWe-year of electrical energy by U.S. LMFBR's by the year 2020 will produce a global population dose commitment of approximately 6 x 10^5 man rem. The global population dose accrued from natural background over this period is approximately 10^{10} man rem.

Because the radioactive half-life of C-14 is long compared to times required for dispersal over large distances, only a small fraction of the population dose from C-14 will accrue in the vicinity of the point of release. Nevertheless, individual and population dose rates will be highest in the vicinity of the release point. For a model 1500 MT LMFBR fuel reprocessing plant releasing 3 Ci of C-14 per year, dose rates from C-14 to individuals and populations in the vicinity of the release are estimated to be only a few percent of dose rates produced by other radioactivity released by the facility which are in turn only a few percent of natural background rates (see 6.2).

3. GENERATION RATES

The calculated rates of ^{14}C production in the several types of reactors planned for use in the U.S. are shown in Table III D-1. The general bases for these calculations are given in Table III D-2. Additional information concerning calculation of ^{14}C production in an LMFBR, including cross sections for various nuclear reactions which produce ^{14}C, can be found in the appendix - Bases for ^{14}C Production Estimates in LMFBR Fuel. The uncertainty in the values given for ^{14}C production in an LMFBR is rather low because the value used in the calculations for nitrogen content of the fuel is based on analytical determinations of these values in LMFBR fuel and because the cross section for the principal nuclear reaction that yields ^{14}C has an estimated error of only $\pm$ 30%.

4. RELEASE RATES

4.1 Fuel Reprocessing Facility

Only that ^{14}C which is converted to gaseous form will escape from a reprocessing plant (in any significant quantity) to the environment. That ^{14}C which is generated in the metal fuel cladding will remain fixed in this material unless it is put into

Table III D-1

CARBON-14 GENERATION RATES, Ci/GWe-yr

	LMFBR	PWR	BWR	HTGR
Fuel	5	13	15	2
Cladding	6	4	5	158
Coolant	-	6[a,c]	16[d]	-
Total	11	23	36	160[b]

[a]This value is taken from a paper by C. Kunz et al., "C-14 Gaseous Effluent from Pressurized Water Reactors," Proceedings of the Eight Midyear Topical Symposium of the Health Physics Society, October 21-24, 1974, CONF 741018, pp. 229-234.

[b]From the report by L. H. Brooks et al., "Carbon-14 in the HTGR Fuel Cycle", GA-A13174, November 29, 1974.

[c]Another estimate - 14 Ci/GWe-yr, U.S. Atomic Energy Commission, "Report on Releases of Radioactivity in Effluents and Solid Wastes from Nuclear Power Plants for 1972", Directorate of Regulatory Operations, 1973 - Yankee Rowe.

[d]C. Kunz et al., "^{14}C Gaseous Effluents from Boiling Water Reactors", Trans. Am. Nucl. Soc. 21, 91, 1975.

Table III D-2

BASES FOR ESTIMATES OF ^{14}C GENERATION RATES

	LMFBR	PWR	BWR	HTGR
Plant thermal efficiency, %	40	33	33	38
Fuel irradiation, MWd/MTU	37,000[a]	33,000	33,000	95,000
Nitrogen content, fuel, ppm	20	20	20	b
Nitrogen content, cladding, ppm	45	40	40	26
Cladding/heavy metal ratio	0.54	0.23	0.23	11
Oxygen ratio, coolant/fuel	-	∿1.5	∿1.5	-

[a]Core and blanket average.

[b]Nitrogen content of fuel is included in the value used for graphite matrix, or cladding.

solution. That portion which is put into solution, or burned in the case of HTGR fuel, is assumed to be converted to gaseous form and mixed with the process vessel off-gas. In the absence of any treatment process to remove the carbon-containing compounds, all the ^{14}C in gaseous form would presumably be released to the environment.

The bases for rates of ^{14}C release to the environment from reprocessing facilities for LMFBR, PWR, BWR, and HTGR spent fuel are shown in Table III D-3. It should be noted that the assumed retention levels in this table are subject to confirmation as development programs proceed.

4.2 Reactor Site

Only the light water reactors generate a significant amount of ^{14}C in the coolant. The amount of ^{14}C which escapes from the fuel or cladding into the reactor coolant is expected to be negligibly small. The quantity of ^{14}C released to the environment could be as much as 16 Ci/GWe-yr if no means are employed to capture the carbon-containing substances in the off-gas, or it might be reduced to 1%, or less, of the above value by use of suitable techniques.

4.3 Uncertainties

The form of ^{14}C in the irradiated fuel is not known at this time; however, no probable chemical or physical form is currently recognized that would render its retention more difficult than has been assumed.

The fraction of the cladding which dissolves is based on experimental data. The estimated fractional releases of ^{14}C are thought to be conservative.

4.4 Chemical Forms of ^{14}C Released

The bulk of the released ^{14}C is expected to be in the form of carbon dioxide, although an amount of it will likely be present as either the monoxide or as short chain alkanes.

5. CONTROL TECHNOLOGY

5.1 LMFBR and LWR Reprocessing Facilities

The process systems for controlling releases of ^{14}C at the reprocessing facility would be essentially identical for LMFBR and LWR fuel, although no action is currently planned for ^{14}C retention at Nuclear Fuel Services or at the Barnwell Nuclear Fuel Plant.

Table III D-3

REPROCESSING FACILITY ^{14}C RELEASE RATES

Reactor Type	Release Rate [Ci/GWe-yr]	Basis
LMFBR	0.05	∿1% dissolution of cladding, 99% retention of volatilized ^{14}C found in fuel and dissolved cladding
PWR	13	No retention of ^{14}C at reprocessing facility - current practice - Negligible quantity of Zircaloy cladding will dissolve
	(0.13)	(99% retention of volatilized ^{14}C using advanced methods)
BWR	15 (0.15)	See PWR
HTGR	1.6	99% retention of all ^{14}C in both the graphite matrix and in the fuel particles

The ^{14}C contained in the ceramic fuel and in that portion of the cladding which is dissolved (corroded away) will probably be converted in the dissolver to a mixture of carbon dioxide and various organic compounds. Some of these organic compounds will be volatile, while others may remain with the liquid phase, perhaps until they are subjected to a stringent chemical condition that will either decompose or oxidize them to CO_2. The ^{14}C will therefore be eventually converted to a gaseous form containing both CO_2 and organic compounds. These latter materials may be converted to carbon dioxide by catalytic oxidation. The carbon dioxide thus formed will then be a minor constituent in the plant off-gas, part of which is shown in Figure 4.4-10 of the LMFBR Program Proposed Final Environmental Statement as passing through a noble gas trapping system. The plant off-gas could be routed through the noble gas system, rather than only that emanating from the shear-dissolver complex. Carbon dioxide is sorbed from air by the fluorocarbon selective absorption process for noble gas trapping with about the same effectiveness as is krypton. Hence, a confinement factor of 100 for ^{14}C that is released within the reprocessing equipment appears to be readily attainable. Some recent experiments with traces of CO_2 in the selective absorption process pilot scale equipment confirm that CO_2 is effectively trapped in this process. An even greater fractional recovery of ^{14}C could conceivably be achieved by the deliberate addition of "normal" carbon dioxide to the noble-gas trapping system feed. As the quantity of ^{14}C dioxide is quite small, addition of relatively little "normal" CO_2 could increase the fractional recovery by a factor of 10. An alternative means for removing carbon dioxide from off-gas involves sorption on molecular sieves; equipment for this operation can be designed and fabricated using existing technology.

The recovered carbon dioxide would be reacted with calcium hydroxide solution, the precipitate dried, canned, and then transported to a suitable disposal facility.

5.2 HTGR Reprocessing Facilities

Instead of being a trace constituent in the off-gas as in the LMFBR and LWR fuel reprocessing case, carbon dioxide will be the principal constituent of an HTGR fuel reprocessing plant off-gas stream. The problem of CO_2 capture (and thus ^{14}C control) is strictly chemical-mechanical in nature. There are several processes by which the recovery could conceivably be made; these range from reaction with a caustic solution to sorption in an amine. The final step in all the processes is conversion of the captured CO_2 to a stable solid, such as $CaCO_3$. There are no readily available data, per se, on a process for this purpose, but available CO_2 recovery information indicates that greater than 99% of the CO_2 could be captured and converted to a stable solid.

5.3 LWR Emissions at the Reactor Site

The ^{14}C content of LWR off-gas could be removed by first converting all the hydrocarbons in the off-gas to CO_2 via catalytic oxidation, and then removing the CO_2 from the off-gas by any of several potentially suitable methods. If a noble gas recovery system is incorporated in the LWR facility, the CO_2 will be removed from the off-gas by this system, whether of the fluorocarbon selective absorption type or of the cryogenic type. An additional step will be required in either of these two processes to route the captured CO_2 to a system to convert it to a stable solid.

5.4 Waste Management

The ^{14}C will generate a negligible amount of heat; however, its toxicity and long life will require that it be sequestered from the environment for a very long period. From an LMFBR, slightly less than half of the total quantity of ^{14}C will be captured in a negligibly small volume of CO_2, while the remainder will be present in the residual stainless steel scrap (leached cladding). This cladding will contain trace amounts of plutonium and fission products, and certain of the basic ingredients of the steel will be activated by neutron irradiation. Per GWe-yr, there will be about 75 tons of this scrap, which may have a density as low as about 200 lb/cf, if it is mechanically compacted, or as high as that of solid stainless steel if the scrap is melted and cast into ingots. About 833 tons of ^{14}C-contaminated $CaCO_3$ will be produced per GWe-yr operation of an HTGR. This material will contain only slightly more than 0.2 curie of ^{14}C per ton.

6. RADIATION DOSES

6.1 Global and U.S. Population Dose

6.1.1 Dose Commitment

Following UNSCEAR,[5] the global population dose commitment (D) over all time following release of C-14 (W) may be estimated from the rate of production of natural C-14 (B) and the average dose rate in human tissue from natural C-14 (γ). For a constant world population (N) of 6×10^9 and a release of 1 Ci this yields:

$$\begin{aligned} D &= \gamma \frac{W}{B} N \\ &= (1.3 \times 10^{-3} \text{ rem/yr})\left(\frac{1 \text{ Ci}}{3 \times 10^4 \text{ Ci/year}}\right)(6 \times 10^9) \\ &= 260 \text{ man rem/Ci} \end{aligned}$$

The U.S. population dose commitment would be approximately 1/20 of this value. This approach provides no indication of the population dose rate as a function of time and assumes a constant C-14 production rate and an unperturbed carbon cycle.

6.1.2 Dose Rate

The time dependence of the population dose rate may be obtained from an approach outlined by Pauling.[6] It is assumed that C-14 mixes rapidly with 2×10^{18}g of carbon in the atmosphere, land biosphere and the mixed layers of the ocean and that mixing with 44×10^{18}g in the deep ocean occurs with a mean life of 30 years. The dose for a constant population of 6×10^9 and a release of 1 Ci is obtained as follows:

$$\frac{1\ \text{Ci}}{2 \times 10^{18} \text{g(C)}} \times \frac{1.3 \times 10^{-3}\ \text{rem/year}}{6 \times 10^{-12}\ \text{Ci/g(C)}} \times 30 \text{ years} \times 6 \times 10^{9} \text{ men} = 20 \text{ man rem/Ci}$$

and $$\frac{1\ \text{Ci}}{46 \times 10^{18} \text{g(C)}} \times \frac{1.3 \times 10^{-3}\ \text{rem/year}}{6 \times 10^{-12}\ \text{Ci/g(C)}} \times \frac{5730}{0.693} \text{ years} \times 6 \times 10^{9} \text{ men} = 234 \text{ man rem/Ci}$$

According to this simple model approximately 10% of the population dose commitment is delivered during the first 100 years following release and 50% of the remainder is delivered over the next 6,000 years. This simple approach does not account for perturbations of the carbon cycle.

There is evidence that the amount of total carbon in the troposphere has been increased over the past decades by the combustion of fossil fuels and combustion at projected rates will result in substantial increases in the future.[7] This effect along with consideration of the buffering action of ocean waters and other factors influencing the carbon cycle is the subject of continuing investigation[7,8] which will refine, but are not likely to greatly change, the magnitude and time dependence of the population dose indicated by these simple models.

6.2 Local Population Doses

6.2.1 Environmental Transport

Gaseous compounds containing ^{14}C, predominantly CO_2, will mix rapidly with the atmosphere in the vicinity of the reprocessing facility after release through the 100-meter stack. During times of release the concentration of ^{14}C will be higher in the local environment until diffusion, transport, and dilution have reduced the concentration.

Natural carbon dioxide mixed with ^{14}C is incorporated into the vegetation, including any crops which man may consume. The ^{14}C is transferred through normal food chain transport to milk, fish, poultry, beef, and other meat products. The principal mechanisms by which ^{14}C enters man's food chain are similar in all environments (local or world wide); however, individual doses will be higher close to the facility. In calculating the biotransport and tissue incorporation of ^{14}C in the immediate vicinity of the LMFBR reprocessing plant, it was assumed that the specific activity of ^{14}C, at each geographical location, was at steady state immediately after release to the environment. This assumption probably results in overestimation of the radiation doses as it takes considerably longer for a steady state to be attained for some materials which will have an appreciable ^{14}C input to man's diet.

6.2.2 Methodology

The principal method used for calculating the dose to man from a steady release of ^{14}C into the atmosphere as CO_2 is based on the assumption that the $^{14}C/^{12}C$ ratio (specific activity) in human tissue approaches a steady-state value which is determined by the prevailing specific activity (1) in the air that an individual breathes and (2) in the local atmosphere at each point of production of his dietary inputs. In particular, if a man lives at a geographic point at which the atmospheric specific activity of ^{14}C in stable carbon is constant and if all of his food is produced where he lives, then the $^{14}C/^{12}C$ ratio of his body tissues will equal the local atmospheric value when equilibrium is achieved. The dose calculations for this analysis assume the equilibrium of man's tissues with the resultant specific activity of ^{14}C in his total carbon intake, in relative proportions with the contributions of the several modes of intake, viz., inhalation and ingestion of food from one or more production sites. This dosimetry is dependent upon the assumption of atmospheric concentrations, at each geographic point of concern, which fluctuate about a mean which is stationary with respect to time.

Analysis indicates that at least 99 percent of the steady-state ^{14}C dose to an organ of man is attributable to the ingestion exposure mode if the ^{14}C specific activity in dietary carbon is equal to that in atmospheric carbon. This assumption is used throughout this discussion.

Dose rate factors are given in Table III D-4 for a number of reference organs. For all internal organs, except the G.I. tract and body fat, the dosimetric information provided by Snyder et al.[9] has been utilized. This reference provides tabulations of factors, S, which represent the dose equivalent (rem) to a target organ per microcurie-day residence of a burden of radionuclide in a source organ. If one substitutes the source organ's steady-state burden in microcuries for the microcurie-days residence, the corresponding factor S may be interpreted as an operator for computing the dose rate (rem/day) to the target organ from that source. The tabulation covers 60 radionuclides, including ^{14}C, and for each nuclide S factors for 22 source and 24 target tissues are given. In the internal dose calculations for Table III D-4, the source and target organs are identical

Table III D-4

CARBON-14 DOSE RATES[a]

	Dose Rate[d] $\frac{mrem/yr}{Ci/m^3}$
Total Body	1.28 E+12
Skeleton	
Endosteal Cells	2.02 E+12
Red Marrow	2.22 E+12
Bone	7.90 E+11
Lung	5.60 E+11
Liver	8.09 E+11
Kidneys	7.24 E+11
Spleen	6.22 E+11
Thyroid	5.87 E+11
Testes	4.97 E+11
G.I. Tract	1.03 E+12[b]
Body Fat	3.70 E+12[c]
Skin Dose From Immersion In Infinite Cloud	4.83 E+8

[a]Computed from W. S. Snyder, M. R. Ford, G. G. Warner, and S. B. Watson, A Tabulation of Dose Equivalent per Microcurie-Day for Source and Target Organs of an Adult for Various Radionuclides, ORNL-5000 (November 1974).

[b]Dose is delivered by contents of lower large intestine plus ^{14}C content of the wall. The model used to estimate the dose due to the contents is that proposed by G. W. Dolphin and I. S. Eve, "Dosimetry of the Gastrointestinal Tract," Health Phys. 12, 163-172 (1966).

[c]Prorated carbon content of yellow marrow to 13.5 Kg fat (63.3 percent).

[d]Computed with the EXREM III computer code: D. K. Trubey and S. V. Kaye, The EXREM III Computer Code for Estimating External Radiation Doses to Populations from Environmental Releases, ORNL-TM-4322 (December 1973).

except for skeletal tissues, in which the dose rates for endosteal cells and red marrow include components of irradiation by bone and marrow. The S factors were not used in the calculation of dose rates to the G.I. tract and body fat; the methods applied to these tissues are discussed later in this section.

The aforementioned dosimetric S factors were computed for biological and physiological parameters which closely approximate corresponding values for the ICRP's Reference Man.[10] It seems probable that future ICRP Publications will present recommendations based on the dosimetry of Reference Man rather than the Standard Man of Publication 2.[11] Other refinements in dosimetry that are applicable to ^{14}C have appeared since ICRP Publication 2: ICRP Publication 11[12] focuses attention on the irradiation of presumably radiosensitive skeletal tissues, such as the endosteal cells, by the ^{14}C content of bone and marrow. The results of such calculations have been incorporated into the dose rate factors presented in Table III D-4.

The dose rate factor for the external dose to the skin from immersion in a semi-infinite cloud was calculated with the EXREM III computer code.[13]

Let Q denote the local activity concentration of ^{14}C in the air (Ci/m^3). Assuming dilution in 0.16 g stable carbon per cubic meter of air, the ^{14}C activity per gram of carbon is

$$Q/(0.16 + 0.223Q), \quad \text{Ci/g C},$$

where 0.223 = g ^{14}C/Ci ^{14}C. Except at very high concentrations ($0.223Q > \sim 10^{-2}$), the approximation Q/0.16, (Ci/g C), may be used. The approximation is used throughout this discussion.

If an organ of man is in steady-state equilibrium with this atmospheric specific activity, its burden B (μCi) of ^{14}C is given by

$$B = 10^6 \, M_C \, Q/0.16 = (6.25 \times 10^6) \, M_C \, Q, \ (\mu\text{Ci})$$

where 10^6 = μCi/Ci and M_C = grams of carbon in the organ. The dose rate $\dot{D}$, (mrem/yr), is

$$\dot{D} = (6.25 \times 10^6) \, M_C \, Q \, S \, (3.65 \times 10^5), \quad \text{mrem/yr}$$

$$= (2.28 \times 10^{12}) \, M_C \, Q \, S (\text{mrem/yr}) \quad , \qquad (1)$$

where 3.65×10^5 converts from rem/day to mrem/yr. With Q = 1 Ci/m^3 this formula has been applied to the calculation of all internal dose rate factors in Table III D-4, with the exceptions previously noted. When source and target organs are identical, the calculation is straightforward. In the cases where endosteal cells, red marrow, and bone are the target tissues, Eq. (1) is applied to each source tissue individually and the partial contributions summed to give the total dose rate. The following summarizes the source-target relationships:

Source Organ	Cortical Bone	Cancellous Bone	Red Marrow	Yellow Marrow
Target Organ				
Bone	X	X	X	
Red Marrow	X	X	X	
Endosteal Cells	X	X	X	X

Body fat is not included as a reference tissue by Snyder et al.[9] because of the difficulty of mathematically defining a mass with indefinite boundaries for the purpose of making Monte Carlo calculations. In Publication 2 of the ICRP,[11] however, body fat is defined as a reference tissue and from a dosimetric point of view becomes the critical organ. Reference Man's total fat weighs 13.5 kg; a reasonable approximation of the carbon content of this tissue is obtained by extrapolation from yellow marrow (63.3 percent carbon) and is 8.55 kg carbon. The ^{14}C activity burden in fat corresponding to an atmospheric concentration of Q Ci/m^3 is

$$(Q/0.16\ Ci/g\ C)x(8.55 \times 10^3\ g\ C)x(10^6\ \mu Ci/Ci) = (5.34 \times 10^{10})Q,\ (\mu Ci).$$

The dose rate $\dot{D}$ (mrem/yr) is calculated as follows:

$$\dot{D} = \frac{(51.2) \times 0.05\ \frac{MeV}{dis}\ \frac{rem}{rad} \times (5.34 \times 10^{10}\ Q\ \mu Ci)}{1.35 \times 10^4\ g\ tissue}$$

$$\times\ 3.65 \times 10^5\ \frac{mrem/yr}{rem/day} = 3.70 \times 10^{12}\ Q\ mrem/yr$$

where

$$51.2 = \frac{3.2 \times 10^9\ \frac{dis/day}{\mu Ci} \times 1.6 \times 10^{-6}\ \frac{erg}{MeV}}{100(erg/g\ tissue/rad)}.$$

The G.I. tract presents a special problem, in that its segments (stomach, small intestine, upper large intestine, and lower large intestine) are irradiated not only by the ^{14}C in their tissues but also by their migrating contents. Thus two components of the dose to each segment were computed. The first, resulting from

^{14}C in the tissues, was derived from Eq. (1), with S given by

$$S = \frac{(51.2) \times 0.05 \frac{\text{MeV}}{\text{dis}} \frac{\text{rem}}{\text{rad}}}{m} \text{ rem}/\mu\text{Ci-day},$$

where m stands for the mass in grams of the segment. For the second component of the dose to each segment, a computer code which implements the model of Dolphin and Eve[14] was employed; the code assumes 95 percent activity absorption of the radionuclide in the small intestine and no absorption of the five percent which passes into the large intestine. This assumption of near total solubility for dietary carbon compounds is in agreement with the Reference Man[10] assumptions about carbon balance. The following shows, for each segment of the G.I. tract, the dose rate factor for each of the two components of the dose, and the total. The lower large intestine is seen to receive the largest dose, with total dose rate factor 1.03×10^{12} mrem/yr per Ci/m^3.

Segment	Dose Rate $\left(\frac{\text{mrem/yr}}{\text{Ci/m}^3}\right)$ ^{14}C in Tissue	Contents	Total
Stomach	7.01×10^{11}	1.57×10^{11}	8.58×10^{11}
Small intestine	6.75×10^{11}	9.99×10^{10}	7.75×10^{11}
Upper large intestine	6.67×10^{11}	1.70×10^{11}	8.37×10^{11}
Lower large intestine	6.94×10^{11}	3.33×10^{11}	1.03×10^{12}

When all intake pathways are in equilibrium with the same atmospheric ^{14}C specific activity, the fraction of an organ dose rate that may be attributed to ^{14}C uptake through inhalation may be calculated as

$$\frac{\text{inhalation uptake rate (g)}}{\text{total uptake rate (g)}} .$$

Reference Man breathes air at the rate of 2.3×10^7 ml/day (8 hr occupational "light activity," 8 hr nonoccupational activity, 8 hr resting).[10] With 0.16 g C/m^3 in the air, the gram intake rate of carbon through inhalation is

$$(2.3 \times 10^7 \text{ ml/day})\times(1 \text{ m}^3/10^6 \text{ ml})\times(0.16 \text{ g C/m}^3)\ f_a = 3.68\ f_a \text{ g C/day},$$

where f_a is the inhalation uptake fraction for the organ of reference. Reference Man ingests 300 g C/day and thus has an ingestion uptake rate of 300 f_w g C/day, where f_w is the uptake fraction for the reference organ through ingestion. Publication 2 of the ICRP[11] provides values for f_a and f_w for several organs, but more generally that publication assumes that these fractions are related by the equation

$$f_a = (0.5 + 0.25/f_1)\ f_w ,$$

where f_1 is the fraction of the radionuclide passing from the G.I. tract to the blood. This equation is, in fact, based on the lung model for particulate matter, which assumes 25 percent retention of such matter in the lungs and mechanical removal of 50 percent, which is swallowed. This model is inappropriate for CO_2 gas, however, and the implied ratio $f_a/f_w = 0.75$ ($f_1 = 1$ for carbon) is probably conservative. Bernard[15] makes an argument which would support a value $f_a/f_w \sim 0.01$ for CO_2 gas. For this discussion the choice is not important; utilization of the conservative value gives the fraction of the organ dose due to inhalation

$$3.68\ f_a/(3.68\ f_a + 300\ f_w) = \frac{(3.68) \times (0.75)}{(3.68) \times (0.75) + 300} = 0.009.$$

The AIRDOS computer code[16] was used to estimate the dose to the local population (people living within 50 miles of the fuel reprocessing plant). The basic equation used to estimate atmospheric dispersion in AIRDOS is Pasquills' Equation[17] as modified by Gifford.[18] The area within 50 miles of the facility was subdivided into 16 sectors (22.5° each) and into a number of annuli. Average annual atmospheric concentrations of ^{14}C attributable to the reprocessing facility release were calculated for each grid subdivision. The average dose for an individual in each grid subdivision was estimated utilizing the individual dose methodology described previously. These dose estimates were multiplied by the number of people in the respective grid subdivision and the resulting products were summed across the entire area. Unless otherwise specified, the dose estimates summed are those for total body, and the unit used to express population dose is man-rem.

6.2.3 Individual Doses

Estimates of dose to an individual at the point of maximum exposure (plant boundary 1000 meters from the stack) due to ^{14}C release from the fuel reprocessing plant are presented in Table III D-5. The estimated values, obtained with the methodology described in 6.2.2., are 50-year dose commitments for one year of ^{14}C release (3 Ci) from the facility. Estimates of dose to an individual at the same location from other radionuclides released by the LMFBR fuel reprocessing facility are summarized in the LMFBR Program Proposed Final Environmental Statement, Vol. II, Section 4, page 4.4-52, Table 4.4-7. The dose estimates presented in the LMFBR Program Proposed Final Environmental Statement are for an adult individual residing constantly at the site boundary and consuming only foods and beverages produced at that location. Those values are also 50-year dose commitments estimated to result from one year of facility operation. The estimates presented there are: 2.0 mrem to total body, 16 mrem to G. I. tract, and 12 mrem to bone. In each case at least 95 percent of the estimated dose is contributed via the ingestion and inhalation exposure modes. The most significant increase that would result from the addition

Table III D-5

ESTIMATES OF 50-YEAR DOSE COMMITMENTS (millirem)*

Organ	At 1000 m boundary[a]	Average person within 50 mi.[b]
Total Body	1.3 E-2	3.1 E-4
Skeleton		
Endosteal Cells	2.1 E-2	4.8 E-4
Red Marrow	2.3 E-2	5.3 E-4
Bone	8.3 E-3	1.8 E-4
Lung	5.9 E-3	1.3 E-4
Liver	8.5 E-3	2.0 E-4
Kidneys	7.6 E-3	1.8 E-4
Spleen	6.5 E-3	1.4 E-4
Thyroid	6.2 E-3	1.4 E-4
Testes	5.2 E-3	1.2 E-4
G.I. Tract	1.1 E-2	2.5 E-4
Body Fat	3.9 E-2	8.9 E-4

[a] χ/Q = 1.1 E-7 sec/m^3

[b] χ/Q = 2.4 E-9 sec/m^3

*To individuals for one year of ^{14}C release (3 Ci/year, 9.51 x 10^{-8} Ci/sec) from the LMFBR fuel reprocessing plant.

of ^{14}C dose contributions would be to the total-body dose. The total-body dose estimate for an adult at the site boundary would be increased to 2.01 mrem per year of facility operation, an increase of 0.5 percent. Estimates of average dose for all individuals living within 50 miles of the facility are also presented in Table III D-5.

6.2.4 Local Population Doses

All population dose estimates presented here are based on the assumption that the released ^{14}C is uniformly dispersed in the atmosphere, and that man and his environment are in equilibrium with the atmospheric ^{14}C concentration resulting from the release (specific activity concept). All values given are for total body as the reference tissue. Estimates of population dose for other reference tissues would scale to the total-body value as the individual dose estimates given for the respective reference tissues in Table III D-4 scale.

The population dose estimates for other radionuclides released from the LMFBR fuel reprocessing facility are summarized in the LMFBR Program Proposed Final Environmental Statement, Vol. II, Section 4, page 4.4-52, Table 4.4-8. The dose estimates given there are 50-year dose commitments calculated for one year of radionuclide release from the facility. Further, details of the calculations (given in Appendix II.I of the same document) indicate that the estimates are for a zero-growth population of one million people living within 50 miles of the facility. The estimated population dose (total body) given there for other radionuclides is 35 man-rem per year of facility operation. A comparable dose estimate for ^{14}C release from the facility is 0.31 man-rem. Thus ^{14}C would not be a major contributor to the total 50-year dose commitment estimated for the local population per year of facility operation, and likewise, it would not contribute significantly to any estimates made of health effects on the local population due to radionuclide releases from the plant.

7. COMPARISONS

The dose potential of the estimated ^{14}C release from the LMFBR fuel reprocessing facility can be compared with the dose potential for estimated releases of other radionuclides from the same facility. The world population dose potential of the annual ^{3}H, ^{14}C, and ^{85}Kr releases from the LMFBR fuel reprocessing facility can be compared using UNSCEAR population dose factors for each. In each case the world population is assumed to be 6×10^{9} people in the year 2000, and to have zero growth. The projected annual release of ^{14}C is 3 Ci and the estimated total world population dose commitment is approximately 780 man-rem. The projected annual ^{3}H

release (LMFBR Program Proposed Final Environmental Statement, Vol. II, Section 4, page 4.4-44, Table 4.4-5) is 1.52×10^5Ci and the estimated total world population dose commitment is 1500 man-rem. The values for ^{85}Kr are 1.22×10^5Ci (Table 4.4-5) and 50 man-rem. Because of its much longer radioactive half-life, the relative importance of the ^{14}C release, on the basis of world population dose potential, relative to ^{3}H and ^{85}Kr releases would be increased by the inclusion of considerations for population growth. The magnitude of the increase would be dependent on the dynamics of the projected population growth.

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APPENDIX TO SECTION III D.1 - BASES FOR ^{14}C PRODUCTION ESTIMATES IN LMFBR FUEL

1. SIGNIFICANT IMPURITY LEVELS IN FUEL AND MATERIALS

Nitrogen content of mixed oxide fuel -- 20 ppm, most of which is present as nitride in the mixed oxide. Specifications for nitrogen permit up to 200 ppm N_2, but experience with LMFBR vendor fuel pellets indicates that the usual content is 10-15 ppm.

Carbon content of mixed oxide fuel -- 20 ppm, although specifications permit up to 150 ppm. The lower figure is representative of LMFBR production pellets.

Nitrogen content of stainless steel cladding and other structural materials -- 45 ppm.

Carbon content of stainless steel cladding and other structural materials -- 0.05%; specification calls for 0.04-0.06%.

Weight ratio of stainless steel cladding and structural materials to heavy metal -- 0.54.

Fraction of above stainless steel and structural materials which is put into solution in dissolver -- 0.0069.

2. BACKGROUND

There are five possible neutron-induced reactions which might be expected to produce significant amounts of ^{14}C:

(1) $^{13}C(n,\gamma)^{14}C$

(2) $^{14}N(n,p)^{14}C$ $(p = {}^{1}H)$

(3) $^{15}N(n,d)^{14}C$ $(d = {}^{2}H)$

(4) $^{16}O(n,{}^{3}He)^{14}C$

(5) $^{17}O(n,\alpha)^{14}C$ $(\alpha = {}^{4}He)$

Other ^{14}C-producing reactions are possible, but probably not important, since they involve the emission of multiple particles (e.g., $^{15}N(n,np)^{14}C$).

3. DATA AND PROCEDURES

The cross-sections used in the calculation of the ^{14}C production rate are of critical importance. Unfortunately, many of these cross-sections are not well known. In the following paragraphs, the energy-dependent cross-section status for each of the five reactions listed above will be discussed. These energy-dependent cross-sections are then collapsed to a single, effective cross-section using a CRBRP neutron spectrum.

Reaction #1 $^{13}C(n,\gamma)^{14}C$

The cross-section data for this reaction are not well known for non-thermal neutron energies. The values assumed were taken from Ref. 1, wherein the $^{13}C(n,\gamma)$ cross-section was calculated based on a few experimental data points and nuclear systematics. The cross-section obtained when the data given in Ref. 1 are collapsed to an effective cross-section using the CRBRP neutron spectrum is 0.5 μb (1 μb = 10^{-6} barns). The fact that the thermal $^{13}C(n,\gamma)$ cross-section is only 0.9 mb coupled with the fact that cross-sections in the non-thermal energy regions are considerably smaller than thermal cross-sections tends to confirm that the 0.5 μb value is realistic.

Reaction #2 $^{14}N(n,p)^{14}C$

Of the five ^{14}C-producing reactions listed, this is the only one where the data may be considered to be adequately known. Energy-dependent cross-section data for the $^{14}N(n,p)^{14}C$ reaction is available from the ENDF/B compilation. Collapsing this data with the CRBRP spectrum gives an effective cross-section of 13.2 mb, with an estimated error of ± 30%.

Reaction #3 $^{15}N(n,d)^{14}C$

The only cross-section data available on this reaction are some sketchy information on the angular distribution of the deuterons when the neutrons have energies of 14-15 MEV. This information, coupled with the fact that the reaction is endothermic (Q = -7.99 MEV), would probably lead to a value of the cross-section in the 0.01 - 0.1 mb range. However, for calculational purposes, a value of 1.0 mb was used.

Reaction #4 $^{16}O(n,^{3}He)^{14}C$

Of the five reactions considered, the data on this reaction are by far the least well known. The reaction is highly endothermic (Q = -14.6 MEV), indicating that neutron energies greater than this are required for the reaction to proceed. Information supplied by the Physics Division of Lawrence Livermore Laboratory indicates that the cross-section at 15 MEV should be less than 1 mb, and at 20 MEV less than 10 mb. By combining these "guesstimates" with the CRBRP spectra and a theoretical expression for the availability of high-energy fission neutrons, the cross-section is estimated to be less than 0.05 μb. It should be noted that this value should be considered an upper limit, although the actual value is subject to great uncertainty due to the lack of information on both the high-energy cross-sections and the high-energy neutron spectrum.

Reaction #5 $^{17}O(n,\alpha)^{14}C$

As with reaction #1, the cross-section data for this reaction are not well known. The data used, which is again calculated data based on a few experimental data points and nuclear systematics, was taken from Ref. 1. The cross-section value calculated using this data and the CRBRP spectrum was 0.12 mb.

To summarize, the cross-sections used are as follows:

Reaction #	Effective Cross-section
1	0.5 μb
2	12.6 mb
3	1.0 mb
4	0.05 μb
5	0.12 mb

The LMFBR fuel model assumed was the Atomics International Follow-On Design.[2] The initial concentrations of the isotopes of importance in this case, in g-atoms/Tonne HM, are:

^{12}C:33.33	^{13}C:0.374	
^{14}N:1.42	^{15}N:0.00528	
^{16}O:8383	^{17}O:3.11	^{18}O:17.1

It should be noted that the ORIGEN code is not capable of explicitly accounting for (n,d) or (n,^{3}He) reactions. This difficulty may be circumvented by combining reaction #4 with reaction #5 and reaction #3 with reaction #2, since the naturally occurring isotopes are present in a fixed ratio for each element. Alternatively, since the depletion of the C,N and O is relatively small (<2%), the calculation is easily performed by hand.

4. DISCUSSION AND RESULTS

Incorporation of the ^{14}C production cross-sections into the ORIGEN code, coupled with some hand calculations, results in the ^{14}C activity produced per unit of parent element given in Table III D-6. On the basis that the fuel contains 20 ppm nitrogen, 20 ppm carbon and stoichiometric oxygen, the resulting amount of ^{14}C is 0.211 Ci/Tonne. The source breakdown of the ^{14}C activity in 1 tonne of LMFBR fuel is given in Table III D-7. The source breakdown for ^{14}C activity in the stainless steel components is given in Table III D-8.

Table III D-6

LMFBR ^{14}C ACTIVITY PRODUCED BY SEVERAL NUCLEAR PROCESSES[a]

Reaction #	Reaction	Ci ^{14}C per unit of parent element[b]	
1	$^{13}C(n,\gamma)^{14}C$	4.81×10^{-9}	$\frac{Ci\ ^{14}C}{ppm\ C}$
2	$^{14}N(n,p)^{14}C$	1.01×10^{-2}	$\frac{Ci\ ^{14}C}{ppm\ N}$
3	$^{15}N(n,d)^{14}C$	2.85×10^{-6}	$\frac{Ci\ ^{14}C}{ppm\ N}$
4	$^{16}O(n,^{3}He)^{14}C$	4.53×10^{-3}	Ci ^{14}C[c]
5	$^{17}O(n,\alpha)^{14}C$	4.03×10^{-3}	Ci ^{14}C[c]

[a]After exposure of 37,000 MWD/tonne.

[b]ppm = parts per million in heavy metal by weight.

[c]Oxygen content based on stoichiometric mixed oxide fuel.

Table III D-7

EXPECTED ^{14}C ACTIVITY IN 1 TONNE OF LMFBR FUEL

Reaction #	Reaction	Ci ^{14}C	% of Total Activity
1	$^{13}C(n,\gamma)^{14}C$	9.62×10^{-8}	4.57×10^{-5}
2	$^{14}N(n,p)^{14}C$	2.02×10^{-1}	95.91
3	$^{15}N(n,d)^{14}C$	5.70×10^{-5}	2.71×10^{-2}
4	$^{16}O(n,^{3}He)^{14}C$	4.53×10^{-3}	2.15
5	$^{17}O(n,\alpha)^{14}C$	4.03×10^{-3}	1.91
Total		2.11×10^{-1}	100

Table III D-8

EXPECTED ^{14}C ACTIVITY IN STAINLESS STEEL COMPONENTS ASSOCIATED WITH 1 TONNE OF LMFBR FUEL

Reaction #	Reaction	Ci ^{14}C	% of Total Activity
1	$^{13}C(n,\gamma)^{14}C$	1.30×10^{-6}	3.05×10^{-5}
2	$^{14}N(n,p)^{14}C$	2.45×10^{-1}	100
3	$^{15}N(n,d)^{14}C$	6.92×10^{-5}	2.94×10^{-2}
Total		2.46×10^{-1}	100

As is evident, the $^{14}N(n,p)$ reaction totally dominates the production of ^{14}C. Since the cross-section for this reaction is reasonably well known, the value of 0.202 Ci ^{14}C per tonne in the fuel should be quite accurate for a nitrogen concentration of 20 ppm.

It is also evident that reactions #1 and #3 contribute in a quite minor way to the production of ^{14}C. Even though the cross-sections for these reactions are only approximate, it is clear that any probable change in these cross-sections would not affect the overall total significantly.

The fact that the ^{14}C production rates via reactions #4 and #5 are still significant (each about 2% of the total) indicates that non-negligible changes in the total ^{14}C production rate might occur as the $^{16}O(n,{}^{3}He)$ or $^{17}O(n,\alpha)$ cross-section data become better known. However, it is felt that the cross-section values used in this analysis erred on the conservative side, and therefore, that the ^{14}C production rates from reactions #4 and #5 are probably too high.

REFERENCES FOR APPENDIX TO SECTION III D.1

1. Alley, W. E. and Lessler, R. M., Semiempirical Neutron-Induced Reaction Cross Sections, UCRL-50484, Rev. 1, August 8, 1972.

2. Atomics International, AI-AEC-12792 - 1000 MWe Liquid Metal Fast Breeder Reactor Follow-on Study Conceptual Design Report (June 1969).

4.6S RADIOACTIVE WASTE MANAGEMENT

A. MIGRATION OF RADIOACTIVITY FROM LOW-LEVEL BURIAL GROUNDS

1. INTRODUCTION

The following paragraph is from page 4.6-46 of the LMFBR Program Proposed Final Environmental Statement, dated December, 1974.

> "...Authorization to operate a commercial land burial facility is based on an analysis of the nature and location of potentially affected facilities; of the site topographical, geographical, meteorological, and hydrological characteristics; and of groundwater and surface water use in the general area which must demonstrate that buried radioactive waste will not migrate from the site. <u>To date, there have been no reports of migration of radioactive material from commercial burial sites.</u> In the unlikely event that there would be such a finding, several courses of action could be taken, including: (1) a halt to burial operations, (2) removal of the radioactive material from the burial area in which it originated, (3) grouting of the site from which the radioactive material originated, or (4) other such procedures that might be necessary, depending on the extent of migration of radioactive material from the site." [underlining added]

Since the Statement was published, there have been reports of the migration of radioactivity from commercial burial areas in Kentucky and New York State.[1,2] These reports, and potential actions to be taken as a result of the migration of radioactivity, are discussed in the following paragraphs.

2. REPORTS OF THE MIGRATION OF RADIOACTIVITY

Conclusions 1 and 2 of the report prepared by the Kentucky Department for Human Resources[1] are as follows:

> "(1) The radioactive waste disposal site at Maxey Flats, Kentucky is contributing radioactivity to the environment. The activity detected in the environment does not create a public health hazard. However, the level of activity detected demonstrates the need to intensify current monitoring activities to provide additional information to determine to what possible extent migration of radioactive material is occurring at the site and for assessing the long range significance of the findings.

(2) The movement of radioactivity from the facility could be through four major routes:

   (a) Surface water run-off.

   (b) Atmospheric fallout from the evaporator plume.

   (c) Migration through geologic formation fissure systems.

   (d) Lateral migration throughout the soil zone."

It has been reported[2,3] that liquids in certain trenches at the West Valley, New York low level waste burial site have seeped out of the trench cover. The seepage was principally limited to onsite areas near the trenches although some seepage drained to the surface water courses at the site. The State of New York has determined that the radioactivity levels in the seepage constitute no hazard to the public health and safety. The site operator has decided to close the site until the details for further studies to assess conditions at the site and procedures for operation of the site are resolved. The following information was obtained from a recent article.[3]

"The Department of Environmental Conservation and NFS have, since early March of 1975, undertaken a comprehensive review of the NFS low level radio-active waste burial facility. The Department's increased concern about the NFS facilities resulted from evidence, which was uncovered as a result of regular DEC monitoring and surveillance programs, that unauthorized release of radioactive water was occurring because of seepage through the cover over the low level waste burial trenches....

"It was only in early March, however, that the Department and NFS representatives found that these accumulations of radioactive water were resulting in seepages to the environment from two of the low level waste trenches....

"On March 11, NFS stopped receiving low level wastes....

"...The recent increase in rate of accumulation may have resulted from the fact that a substantial portion of the cover of these trenches had settled during the winter, creating a catch basin effect. Normally, the cover on the trenches is kept mounded to prevent water accumulation or seepage into the trenches.

"It is also possible, however, that the increased accumulations of water in these two trenches, as well as at least one other trench on the burial site, resulted from underground infiltration. DEC and its consultants and NFS are accelerating studies to find out the cause of these accumulations of water in the trenches.

"Over the next few months, the Department of Environmental Conservation will be undertaking a comprehensive review of the NFS low level waste burial operations and facilities."

The following paragraph was provided by the New York State Department of Environmental Conservation to update the information already provided.[4]

"In order to prevent the further physical breakthrough of radioactivity through the cover, 225,000 gallons of water were pumped from three of the trenches to the low level waste lagoon system at the NFS reprocessing plant. The water was intermixed with wastes from the plant and then treated at the NFS low level waste treatment plant to remove strontium, cesium and plutonium isotopes. Tritium was not removed by the treatment. After treatment the water was discharged to the local water courses in accordance with procedures agreed to by NFS and the Department of Environmental Conservation."

Editorial note - *NFS's low level burial site is licensed by the State of New York. The Department of Environmental Conservation has been monitoring the adjacent streams and took over the State's burial permit function from the Department of Health in October of 1974. New York State exercises this authority under an agreement with the Federal government that permits states to assume the licensing for such low level radioactive waste burial facilities.*

3. DISCUSSION

The following information is taken from the report by the Kentucky Department of Human Resources.[1]

"The Nuclear Engineering Company, Inc. (NECO) of Louisville, Kentucky operates a radioactive waste disposal site at the Maxey Flats area in Fleming County, Kentucky. The operation of this site is under authorization of a radioactive material license issued by the Radiation and Product Safety Branch of the Department for Human Resources. Regulation of the operation is also under the Kentucky Department for Natural Resources and Environmental Protection, Division of Air, Division of Water, and Division of Solid Waste. The Department for Human Resources is the primary regulatory agency under the terms of a Kentucky-U. S. Atomic Energy Commission (AEC) regulatory agreement. This radioactive disposal facility was started in 1963. The Radiation and Product Safety Branch, Environmental Radiation Laboratory has maintained a comprehensive pre and post-operational radiation monitoring program at the facility since March, 1963. Also, NECO has conducted a radiation monitoring program.

"During the first ten years of operation, no detectable quantities of radioactivity, above natural background, on a repeated basis, had been observed. In 1971 a proposal for future studies at the waste disposal facility was recommended by members of the Radiological Health staff. The basis for this recommendation was due to:

(1) increasing quantities of radioactive materials, particularly large quantities of special nuclear material, being disposed of at the site;

(2) staff concern about the containment of buried waste relating to water management aspects.

"In 1972 certain environmental monitoring data began to indicate a possible initiation of radioactivity contribution to the immediate Maxey Flats site area. On November 15, 1973, a six month special environmental radiation monitoring study of the radioactive waste disposal facility was initiated. The study was designed, within the constraints of available resources, to qualitatively and quantitatively identify the source and scope of increased levels of environmental radiation previously discovered in the area...."

In addition to items (1) and (2), the Kentucky report[1] concluded...

"(3) Existing geological mechanisms are not effective in maintaining tritium waste within the disposal trenches. (The rate of tritium migration was not determined by the study.)

(4) Man-made radionuclides measured in certain individual samples collected in the unrestricted environment identified Tritium, Cobalt 60, Strontium 89 and 90, Cesium 134 and 137, and Plutonium 238 and 239.

(5) Plutonium concentrations measured in certain individual samples collected in the unrestricted environment and Test Wells exceed ambient levels...."

The following information is taken from the press release of the New York State Department of Environmental Conservation.[2]

"'While D.E.C. monitoring of the burial site has observed recent increases in the level of radioactivity around the burial site, the Department has not found from water tests this week any significant increase in radioactivity in Buttermilk Creek,' Commissioner Reid said.

"'The rising level of radioactive contaminated water in the trenches and the potential release of radioactivity such as Strontium 90 from the burial site into Buttermilk Creek, Cattaraugus Creek and ultimately Lake Erie, are matters of concern to the Department', Commissioner Reid said. 'Departmental representatives reported that a substantial portion of the cover of one burial trench had settled, creating a catch-basin effect. This resulted in a rising level of water in the trench and seepage of radioactive water out of the cover of the trench.'"

Thus there seems to be little doubt that there has been some migration of radioactivity, including tritium and plutonium, from two commercial burial areas. There have been no such reports from the other commercial areas. The processes and principles for the migration of radioactivity are somewhat unknown, but it appears that surface water run-off is one factor. However, underground infiltration cannot be ruled out at present.

Furthermore, there appears to be general agreement that additional measurements of the migration of radioactivity from the commercial burial areas in Kentucky and New York State are needed and that the total migration that has occurred to date does not constitute a significant public health hazard. The U.S. Geological Survey (USGS) is initiating a study of commercial low level waste burial areas to obtain information required to develop guidelines for evaluating future burial sites and, if possible, to develop predictive models to assess the extent of transport of waste in different geological formations. The Survey's five-year study will use field data from the state-owned burial sites and theoretical and laboratory solute transport data to construct predictive models for different hydrogeological environments.[5] Waste solute transport models can be used to predict how fast and in what direction waste will move from burial sites. The data analyses and interpretation will develop better geologic and hydrologic criteria for use in evaluating waste burial sites. Completed studies will provide data that will be useful in the monitoring and management of existing sites. Also, EPA is conducting environmental studies and pathway analyses at the Maxey Flats site to better evaluate the significance of the public health hazards. Kentucky has established a committee of Federal and State representatives to design detailed studies to further evaluate the Maxey Flats site. New York State has retained consultants and plans to work closely with the site operator in carrying out further studies at the West Valley site.

4. CONCLUSIONS

It is concluded that the migration of radioactivity from two commercial low level waste burial areas is a problem requiring resolution for the nuclear power industry in general but is not an immediate concern for the LMFBR Program. It is expected that the studies previously discussed will disclose the processes and principles for the migration of radioactivity and appropriate steps can be developed to reduce further migration from these areas. It is also expected that improved criteria for determining the suitability of commercial low level burial areas will be developed before significant quantities of low level wastes from the LMFBR fuel cycle are sent to such burial areas. Now that the problem has been identified at commercial burial grounds and ERDA sites,[6] steps are being taken to mitigate the consequences of existing migration[4,7] and to develop improved burial ground siting criteria.

REFERENCES FOR SECTION III D.2.A

1. Project Report, "Six-Month Study of Radiation Concentrations and Transport Mechanisms at the Maxey Flats Area of Fleming County, Kentucky," by Kentucky Department for Human Resources, Bureau for Health Services, Office of Consumer Health Protection, Radiation and Product Safety Branch, December, 1974.

2. Press Release, New York State Department of Environmental Conservation, March 13, 1975.

3. Article, "Nuclear Fuel Services' Burial Facility Review Underway," NYS Environment, April 1, 1975.

4. Letter, T. J. Cashman, Director, Bureau of Radiation, New York State Department of Environmental Conservation to G. L. Sherwood, ERDA, July 31, 1975.

5. Letter, V. E. McKelvey, Director, USGS to C. L. Dawson, Secretary for Human Resources, Commonwealth of Kentucky, May, 1975.

6. ORNL-5017, "Status Report on Radioactivity Movement from Burial Grounds in Melton and Bethel Valleys," J. O. Duguid, Oak Ridge National Laboratory, July, 1975.

7. "Report of the Nuclear Regulatory Commission Review Group Regarding Maxey Flats, Kentucky, Commercial Radioactive Waste Burial Ground," July 7, 1975.

B. WASTE MANAGEMENT PROGRAM PLAN

1. INTRODUCTION

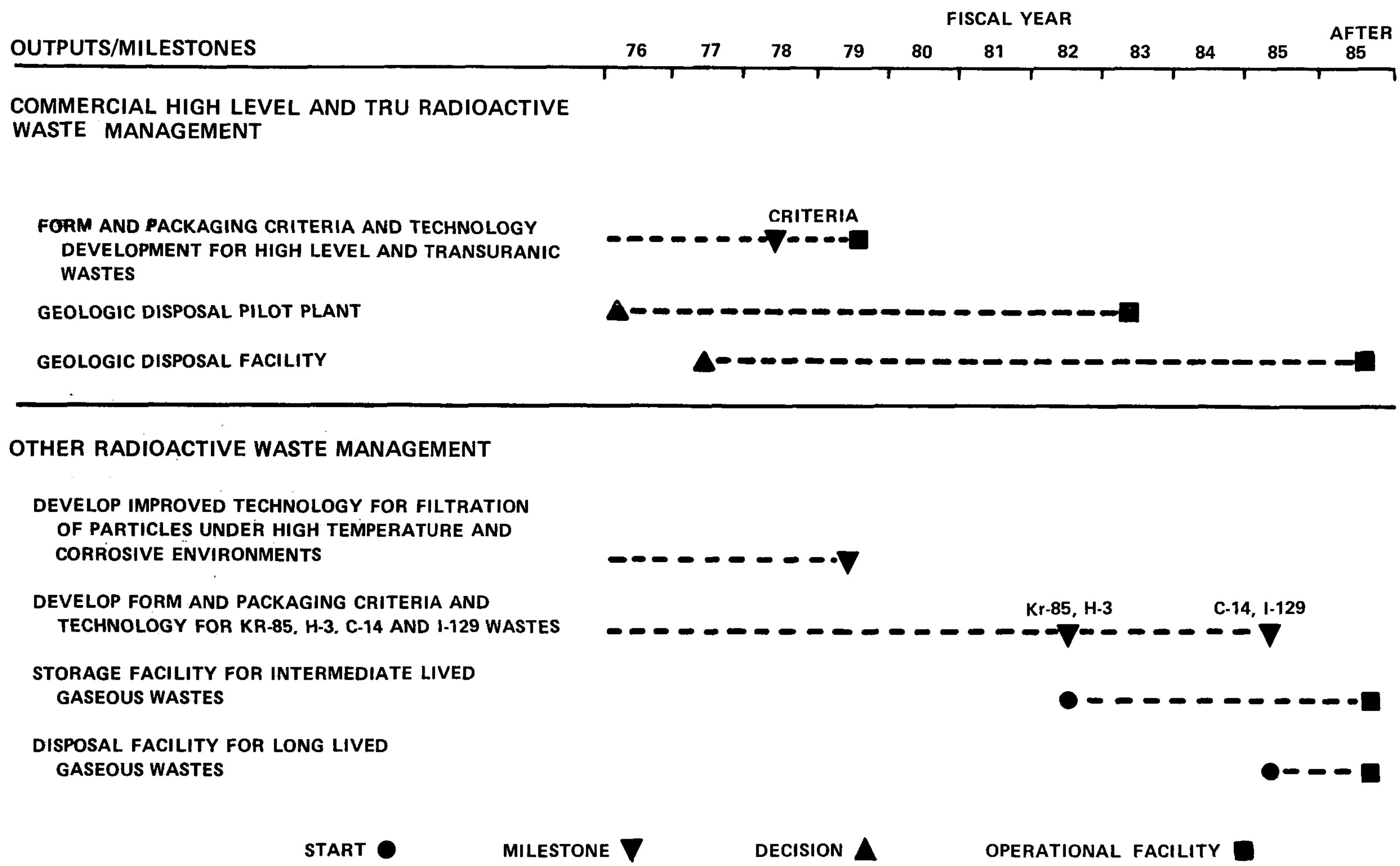
This preliminary waste management program plan is derived from material contained in ERDA-48, "A National Plan for Energy Research, Development and Demonstration: Creating Choices for the Future," Volume 2: Program Implementation. This plan covers only that part of the overall waste management program plan (presented in ERDA-48) dealing with commercial radioactive wastes. Plans for managing ERDA radioactive wastes, primarily resulting from the production of materials for nuclear weapons, are not included in the program plan presented here.

Figure III D-3, a schematic representation of the radioactive waste management program plan, with outputs and tentative milestones, shows the various individual topics discussed separately in the following sections. Although a considerable amount of research and development on many of these topics has already been completed, completed research and development is not discussed here. Only ongoing and new research, development and demonstration efforts are presented. Lastly, it should be noted that the contents, timing, milestones and priority of the following efforts may be changed as new information is developed during the execution of the program.

2. TECHNOLOGY DEVELOPMENT FOR COMMERCIAL HIGH LEVEL AND TRANSURANIC WASTES

Regulations require that aqueous highly radioactive waste from commercial spent fuel processing plants be converted to a stable solid within five years of its generation. ERDA has a continuing program for development of technology for conversion of waste to massive low-leachable forms. Primary emphasis has been given to the silicate glass form. However, studies are also in progress on ceramic waste forms that may provide advantages in processing stability. The program will be continued: (1) to confirm the long-term stability of the glass calcine and alternate ceramic waste forms that have been developed; (2) to develop and test equipment required for conversion of the radioactive waste to the glass and ceramic forms; and (3) to operate a pilot plant using selected processes with simulated radioactive wastes.

In 1974, the NRC (then AEC) published for comment a proposed regulation which would prohibit further burial of commercial transuranic wastes in soil and require such waste to be transferred to Federal custody. If the regulation becomes effective, ERDA plans to store most of the received material at one of the large existing ERDA sites, using the methods developed over the past several years for storing the large volumes of Rocky Flats plutonium-contaminated waste. Adaptation of pad



WASTE MANAGEMENT PROGRAM PLAN

Figure III D-3

storage, or modification of processing cells in existing buildings, will probably be provided for the "hulls," or fuel cladding residues, which, in addition to transuranics, are contaminated with radioisotopes that have penetrating radiations.

Commercial transuranic wastes will be generated primarily in spent fuel processing and plutonium fuel fabrication plants. In anticipation of the growing commercial transuranic-contaminated solid waste problem, a broad development program will be continued to evaluate all aspects of this commercial problem, especially methods for reducing the radioactive content and volume of waste generated, as well as for further reducing the volume of the waste which must be stored or disposed of.

In the preparation of irradiated fuels for chemical processing, short segments of quite highly contaminated zirconium fuel cladding-tubing end up as waste. There is a need to stabilize the zirconium, and to reduce its volume for safe and economic storage as a solid waste. There will be a continued effort to establish technical feasibility for treatment methods which have been identified as promising approaches in previous theoretical studies. To date, chemical decontamination of cladding hulls followed by melting or mechanical compaction appear to be the most promising methods. Studies will also be directed toward possible recovery of the zirconium and reuse by the nuclear industry. Treatment methods for solidifying or decontaminating cladding hulls will be developed.

3. RETRIEVABLE SURFACE STORAGE

Except for about 600,000 gallons of commercial high-level radioactive waste produced in the late sixties and currently stored as a neutralized solution in carbon steel tanks on land owned and controlled by the State of New York, essentially no commercial high-level radioactive waste exists today. Until the commercial spent fuel processing plants commence operation, the spent fuel from commercial nuclear power reactors will be stored either at the reactors, at one of the processing plants, or possibly at special facilities constructed and licensed especially for this purpose.

Various methods for the safe retrievable storage of highly radioactive, heat generating waste material have been studied and evaluated. Three approaches - water cooled basin, air cooled vault and shielded air cooled individual container - have been shown to be capable of safely containing the canistered waste for decades - or even for centuries - should this be necessary. Each can be built and operated within existing technology. Studies have also shown that, from a technical standpoint, any one of the three large western ERDA sites - Hanford, Idaho, and Nevada - could be acceptable sites for storage.

In 1974, in compliance with the National Environmental Policy Act (NEPA), NRC (then the regulatory arm of the AEC) published a draft generic environmental impact statement on the recycle of plutonium as a fuel in water reactors, and ERDA (then the operating arm of the AEC) published a draft environmental impact statement on its plans to manage the high-level and transuranic radioactive waste material which it would receive from licensed commercial operations under existing and proposed NRC regulations. Since publication of these two draft statements, written public comments - and, in the case of the waste management statement, verbal testimony at two public hearings - have been critical of the scope and content of each.

While no final action has been taken by the NRC with regard to the "plutonium recycle" question, it has indicated* to the industry its provisional views that pending resolution of this problem, it should not grant approval for further construction, plant modification or operation of spent fuel processing or plutonium fuel fabrication plants. This delay in the date of initial operation of the "waste producing" plants - and more importantly of the facilities for solidification of the aqueous high-level radioactive waste - means that the time when ERDA will receive packaged high-level waste is more likely to be in the mid to late eighties rather than the early eighties, and the rate of deliveries after the initial receipts will be much less than originally anticipated.

ERDA, after a careful review of the comments on its statement on management of commercial radioactive waste, and with knowledge of the potential delays in approval of waste generating plants just mentioned, decided to withdraw the draft waste management statement and to issue a new draft with a much expanded scope to cover all options of management from the time the spent fuel is removed from the reactor until all the radioactive wastes generated by nuclear reactors have been disposed of safely.

This expanded statement will require twelve to eighteen months to prepare in draft form. Another six to twelve months will be required to receive written comments, hold public hearings and issue a final document which considers the comments. Based on this time schedule, it is impossible to take any affirmative action on construction of facilities to manage commercial radioactive waste for at least two years.

*Federal Register, Vol. 40, NO. 90, Thursday, May 8, 1975.

ERDA plans to use this time for a much expanded research and development program on bedded salt and other disposal methods - with the objective of having acceptable disposal methods demonstrated at the earliest possible time. This will minimize the ultimate impact of the initial delays and, depending on the timing of the resolution of the plutonium recycle question, could possibly eliminate the need for, or at least reduce the magnitude of, the program for retrievable surface storage which had previously been a keystone of the ERDA waste management program.

4. GEOLOGIC DISPOSAL PILOT PLANT

ERDA has recently restarted a program leading to the construction of a "pilot" disposal facility in bedded salt in southeast New Mexico. When this facility is ready to receive radioactive waste in the early eighties, treated plutonium waste from ERDA storage facilities will be the first material emplaced therein. As the programs on solidification and packaging of high-level waste proceed to a point where sealed canisters of waste, ready for disposal, are available, the pilot facility may be used to further study the high-level waste disposal capabilities of bedded salt. The latter studies and other studies which will be made on the technical, safety and economic aspects of disposal of high-level waste will form an important part of the overall program for isolation of commercial high-level waste and will provide required technical support for one or more additional facilities for such wastes.

The initial objective is to provide the facilities and capabilities to permanently dispose of ERDA transuranium waste. This objective is achievable with proven existing analytical capabilities and technology. Limited quantities of transuranium waste will be received and placed in the salt bed in a fully retrievable condition. Pilot plant operations will be continued until the observations and measurements made have demonstrated the safety and acceptability of the disposal mode, after which the pilot plant may be converted to a full capacity disposal operation wherein the waste will no longer be readily retrievable.

The principal effort in FY 1976 will be aimed at the development and accumulation of the data needed to support a budget request for a FY 1978 construction project. In order to accomplish this goal, site selection investigations will be completed, a site will be selected, and a final site evaluation report will be prepared. An architect engineer will be selected and work initiated on the development of a conceptual mine arrangement and facility layout that can be used as the basis for the project cost estimate to be included in the budget documents. Rock mechanic evaluations of alternative mine arrangements will be continued until a specific concept is selected for inclusion in the facility conceptual design report. Work will be carried out on the analyses and accumulation of data needed for inclusion in an Environmental Impact Statement. A bore hole/mine shaft plugging program which utilizes existing plug materials and plug emplacement techniques will be expanded and an instrumented plugging demonstration performed in the field.

5. GEOLOGIC DISPOSAL FACILITY

In addition to the developmental effort on bedded salt, ERDA plans to continue the investigation of other geologic formations that can also potentially be used for permanent disposal of radioactive waste materials. This program will continue the investigation of the occurrence and properties of formations such as granite, shale, limestone, mudstones, clay and salt domes. Field surveys will be conducted to determine the geologic and hydrogeologic environments that influence the integrity of such formations against groundwater intrusion and movement. The program will also evaluate and investigate possible techniques of cavity formation such as mining, tunneling, drilling, explosive fracturing or sluicing suitable storage cavities; methods of waste emplacement within the cavity; and finally, design experiments and tests that will provide the confirmatory data and engineering basis for assuring that permanent disposal can indeed be conducted in a selected system. Seabed disposal is also being investigated. The objective of these studies is to obtain that information on formations, other than bedded salt, required for future decisions on the type and location of a geologic disposal facility (or facilities) for high-level and transuranic wastes.

6. OTHER RADIOACTIVE WASTE MANAGEMENT

At the present time, most of the long-lived gaseous fission products generated in reactor fuel are released at the spent fuel processing plants. The principal radioactive isotopes involved are tritium, krypton-85, iodine-129, and carbon-14 (released as carbon dioxide). Both EPA and NRC are currently considering regulations for these gases which may prevent their emission at commercial plants in the mid 80's.

Work has been under way for some time at ERDA laboratories to develop ways to remove these radioactive gases from plant effluents and some of the developments have been efficiently applied at ERDA facilities. This development program is aimed at providing the technology needed to safely fix and store these wastes. Investigations of solidification techniques for each of these gases are now under development on a laboratory scale and pilot demonstrations are planned in 1978 for tritium and iodine, and 1979 for krypton.

Improving the collection and handling of radioactive airborne particulate wastes is another important aspect of this program. The principal objective is to improve the efficiency and reliability of filtration systems for plutonium facilities and to reduce the volume of plutonium contaminated filters requiring storage as waste.

It is expected that two facilities for management of these gaseous wastes will be required - one for storage of relatively short-lived wastes (tritium and krypton) and one for disposal of long-lived wastes (carbon-14 and iodine-129). This latter waste may be placed in the geologic disposal facility. As shown in Figure III D-3 such facilities are expected to be available after 1985.

SECTION III E

ASSESSMENT OF U.S. URANIUM RESOURCES

6A.1.1.2S THE ASSESSMENT OF U.S. URANIUM RESOURCES

1. Background

U.S. uranium resources are discussed in PFES Volume III, Sections 6A.1.1.2, 6A.1.1.8 and 6A.1.1.9 and in PFES Volume IV, Section 11.2.3.7. The relatively high grade uranium resources in the U.S. are found mostly in western sandstones. ERDA estimates as of January 1, 1975 indicate resources of 2.7 million tons of U_3O_8 in this type of ore and an additional 0.8 million tons in non-sandstone ores, all within the ERDA $30 category.* However, less than 20% of these resources are in the ore reserve category;** the balance represents estimated potential resources.

There are more extensive deposits of uranium in geological formations such as shales and granites in the U.S., but the uranium concentration is so low in these formations that technical, economic and environmental constraints will probably inhibit or prevent their exploitation on a large scale.

Over the long term, prospects for significantly augmenting U.S. uranium resources with imported uranium are not good, unless new discoveries add appreciably to currently estimated foreign resources. The installation of non-breeder nuclear capacity abroad is proceeding at a rapid pace and is projected to grow such that all currently estimated foreign uranium resources (non-communist countries) evidently will be needed to support this nuclear capacity.

In terms of U_3O_8 requirements to support LWR and HTGR plants over their service lives, a U.S. resource base of 3.5 million tons of U_3O_8 could be fully committed before the end of the century, assuming moderate growth in LWR and HTGR additions to installed electric generating capacity in the U.S., and taking into consideration the amount of uranium that must be available in reserves to support needed rates of supply. This possibility argues in favor of early commercial introduction of the LMFBR, beginning about 1990.

On the other hand, the need for the LMFBR - or at least the need for its early commercialization - has been questioned† on the thesis that there is an abundance of reasonably economic uranium in the U.S., waiting to be discovered. It is argued

*i.e., forward production costs per pound of U_3O_8; not to be interpreted as sales price in the marketplace. See Table III E-1.

**Reserves represent uranium in known deposits for which detailed information is available, usually from surface drilling.

†See Comment Letters in PFES: 14, p. V.14-1; 38, pp. VI.38-203 to -211; and 55, pp. VII.55-4 to -7.

that the ERDA estimates are low because they are based largely on knowledge of producing areas and known geologically favorable areas, which collectively occupy only a small fraction of U.S. land area. It is postulated that further exploration will reveal economic uranium resources sufficient to support a growing non-breeder nuclear power industry well into the next century. On this basis, it is further argued the the LMFBR could be developed at a more leisurely pace, or perhaps could even be by-passed by alternative technologies now under development.

The issue that has been raised is highly speculative, because no hard information exists to support the postulation of abundant, relatively low cost uranium resources in the U.S. beyond those included in the ERDA estimates. By the same token, however, insufficient information exists to permit a confident projection of the ultimate availability of low cost uranium resources in the U.S.

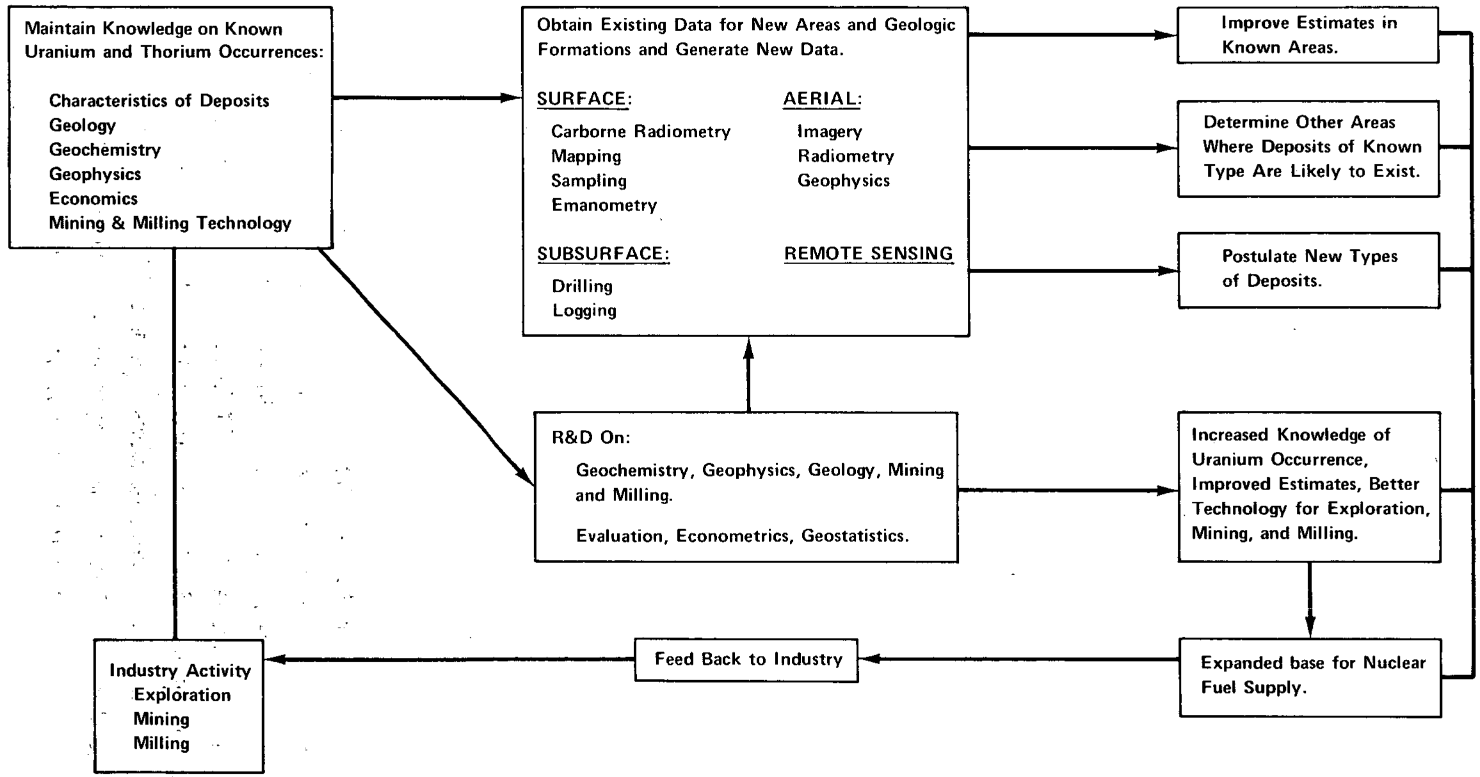
2. The National Uranium Resource Evaluation (NURE) Program

In view of the need to better understand the long-range prospects for expanded domestic uranium supply, ERDA is carrying out programs to more completely assess domestic resources and to improve technology for discovery, assessment, and production of these resources. The basic elements in the ERDA resource program are illustrated in Figure III E-1.

Knowledge on known uranium occurrences will be augmented by gathering and generating new data by use of surface, aerial, subsurface and remote sensing techniques. This will allow improved estimates in known areas and identification of other areas where known types and postulated new types of deposits may exist. Information developed from these activities will routinely be made available to industry for development of their exploration and mining programs. Industry efforts will generate additional data which will also be used by ERDA in continuing resource studies. An important part of this strategy is research and development to improve the technology involved in all aspects of uranium discovery, assessment, mining and milling.

ERDA uranium raw materials budgets to carry out this program are increasing. In FY 1974, expenditures were around $2 million. In FY 1975, the budget increased to around $6 million, and a $14 million program is budgeted for FY 1976. Further increases are expected.

Two activities underway to generate new data systematically are the aerial radiometric reconnaissance program and the national hydrogeochemical survey.



BASIC ELEMENTS OF THE NURE PROGRAM

Figure III E-1

Features of the airborne program are highlighted in Figure III E-2. This program involves some 741,000 line miles of aerial surveys to be flown on an average line spacing of five miles, utilizing gamma ray spectrometric techniques. Data generated are being made publicly available upon the completion of individual projects.

The hydrogeochemical survey features are listed in Figure III E-3. This is a systematic national survey of the uranium and associated trace element content of surface and underground waters and stream sediments. It will involve the National Laboratories, universities, state agencies, and the U.S. Geological Survey. Data generated will provide a means of identification of areas of favorability, particularly when coupled with other available data.

The ERDA programs involve a continuing review of the uranium resource situation, analysis of the activities and success of industry and their relation to the desirable resource levels needed in the years ahead to assure adequate uranium supplies to meet the country's needs. The program is geared to providing information to government and industry.

3. Results from the NURE Program to Date

The potential uranium resources estimated as a result of the National Uranium Resource Evaluation program thus far are shown in Table III E-1. These estimates stem from the project areas for which surveys were completed as of the end of 1975 (Figure III E-4). These areas constitute the most favorable known areas in the United States. However, a number of areas in the West and most of the East remain to be assessed. Information providing a basis for evaluation of uranium resources is most complete in the western states, particularly in and around the known uranium mining districts. Much additional information will be required before a reliable assessment of the rest of the country can be made.

Relative to the resource estimates at the beginning of 1974 (see Table 6A.1-2, PFES Volume III), current estimates are about a million tons of U_3O_8 higher. It is interesting to note that most of the additional potential is attributed to non-sandstone deposits, as shown in Table III E-2. Also, the assessment of U.S. uranium reserves as of January 1, 1975 is lower than the estimate at the beginning of 1974. A large reduction occurred in the $8/lb. category, a reduction from 277,000 to 200,000 tons. The primary reason is a reevaluation to reflect the inflationary effects of the past few years, but reevaluation based on new data also contributed to the decrease. The uranium removed from the $8 category largely

GOAL – COMPLETE AIRBORNE RADIOMETRIC SURVEY OF U.S., INCLUDING ALASKA, ON WIDE-SPACED FLIGHT LINES, BY 1-1-80, TO AID IN IDENTIFYING FAVORABLE AREAS.

PROGRAM – TOTAL LINE MILES FLOWN – CONTERMINOUS U.S., 600,000; ALASKA, 100,000

FLIGHT LINE SPACING – 2-12 MILES: AVERAGE 5 MILES

ALTITUDE – 200-800 FEET ABOVE GROUND LEVEL, OPTIMUM 400 FEET

SYSTEMS – COMPUTERIZED HIGH-SENSITIVITY GAMMA-RAY SPECTROMETRIC AND MAGNETIC DETECTORS, MOUNTED IN FIXED-WING AND ROTARY-WING AIRCRAFT OPERATED BY PRIVATE FIRMS

OUTPUT – RADIOMETRIC EQUIVALENT OF URANIUM, THORIUM, AND POTASSIUM, AND MAGNETIC CHARACTERISTICS OF ENCLOSING ROCK, STATISTICALLY EVALUATED BY GEOLOGIC UNITS

DATA HANDLING

PUBLICATION – OPEN FILE UPON COMPLETION OF EACH SURVEY

SUMMARIZED DATA BANK – LOS ALAMOS SCIENTIFIC LABORATORY

TENTATIVE SCHEDULE

FISCAL YEAR	NO. AREAS	LINE MILES
1974-75	7	44,000
1976	13	81,000
1977	22	171,000
1978	43	245,000
1979	40	200,000
	125	741,000

AERIAL RADIOMETRIC RECONNAISANCE PROGRAM

Figure III E-2

GOAL – A SYSTEMATIC DETERMINATION OF THE DISTRIBUTION OF URANIUM AND ASSOCIATED TRACE ELEMENTS IN SURFACE AND UNDERGROUND WATERS AND IN STREAM SEDIMENTS IN THE U.S., INCLUDING ALASKA, TO IDENTIFY AREAS FAVORABLE FOR URANIUM MINERAL OCCURRENCE.

PARTICIPANTS:

NATIONAL LABORATORIES; UNIVERSITIES; STATE AGENCIES; U.S.G.S.; E.P.A.

OPERATING PARAMETERS:

SAMPLE SPACING – 10 SQ. MI. (WIDE AREA) – 1/2 SQ. MI. (DETAILED) DEPENDING ON GEOLOGIC HOMOGENEITY OF AREA.

ANALYSIS – FIELD CONCENTRATION OF ELEMENTS FROM WATER; MEASUREMENT OF CONDUCTIVITY AND pH; DETERMINATION OF SPECIFIC ELEMENTS.

DATA TREATMENT – STATISTICAL ANALYSIS.

DATA INTERPRETATION – RELATE ANOMALY DATA TO GEOLOGIC ENVIRONMENTS.

OUTPUT – AREAS OF FAVORABILITY; OPEN-FILING OF MAPS AND DATA; NATIONAL DATA BANK.

TENTATIVE SCHEDULE:

FISCAL YEAR – 1975 - LITERATURE SEARCH AND LIMITED R&D.
1976 - PILOT STUDIES; STATISTICAL METHODS DEVELOPMENT; STAFFING.
1977-1979 - LARGE-SCALE SURFACE AND SUBSURFACE SAMPLING; DATA ANALYSIS, INTERPRETATION AND REPORTING.

STUDIES IN PROGRESS OR UNDER NEGOTIATION:

ERDA SAVANNAH RIVER LAB.; PENN STATE UNIVERSITY; ALASKA DEPT. OF MINERAL RESOURCE

HYDROGEOCHEMICAL SURVEY

Figure III E-3

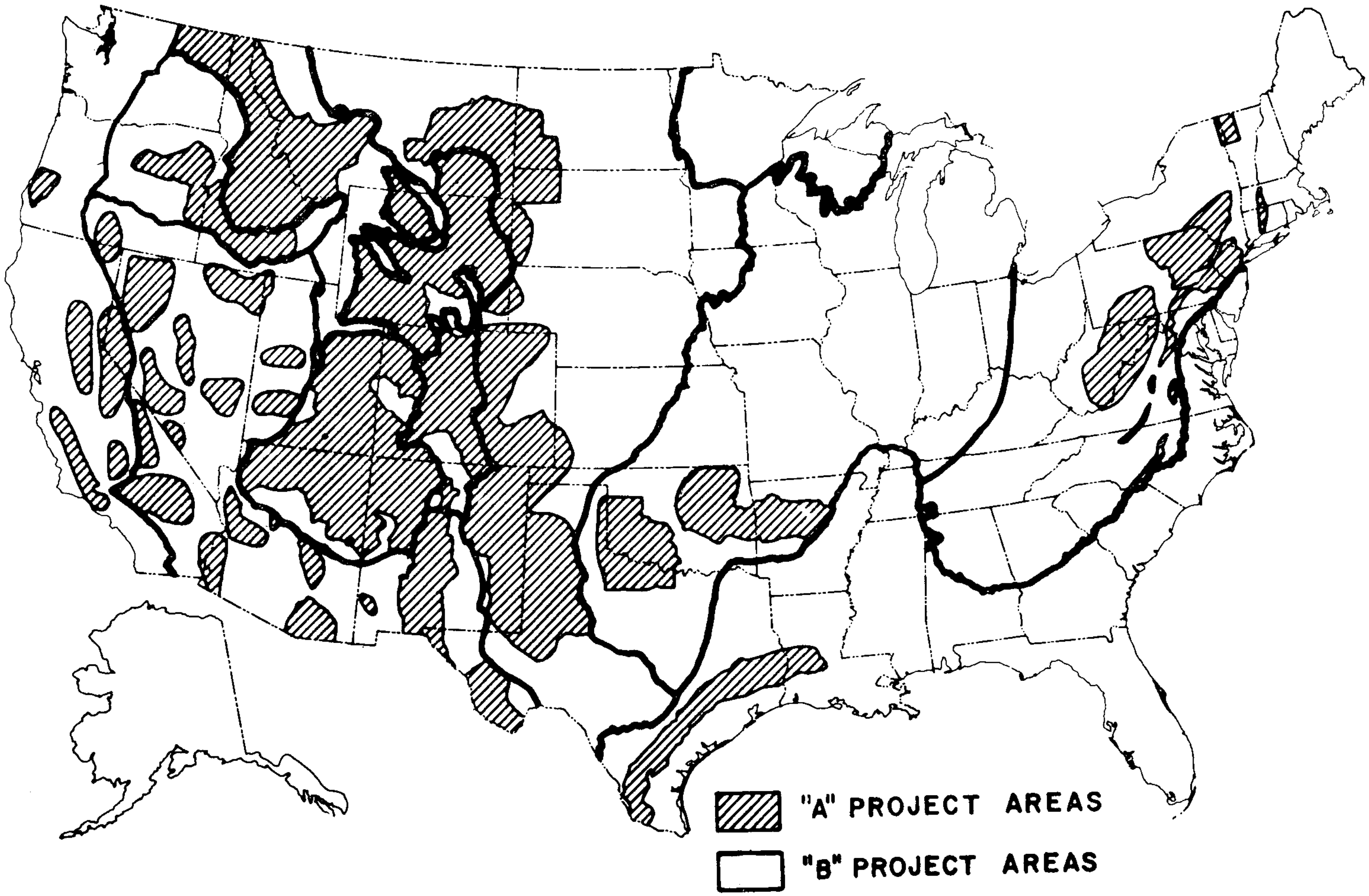
Table III E-1

ESTIMATED U. S. URANIUM RESERVES AND POTENTIAL RESOURCES, December 31, 1975

Tons U_3O_8

	Reserves	Potential: Probable	Potential: Possible	Potential: Speculative	Total
$10	315,000	440,000	420,000	145,000	1,320,000
$10-15 Increment	105,000	215,000	255,000	145,000	720,000
$15	420,000	655,000	675,000	290,000	2,040,000
$15-30 Increment	180,000	405,000	595,000	300,000	1,480,000
$30	600,000	1,060,000	1,270,000	590,000	3,520,000
By Product*					
1975-2000	90,000	-	-	-	90,000
2000-2020	150,000				150,000
	840,000	1,060,000	1,270,000	590,000	3,760,000

* By-product of phosphate and copper production.



NURE PROJECT STATUS IN 1975

Figure III E-4

Table III E-2
POTENTIAL RESOURCES IN NON-SANDSTONE AREAS

	TONS U_3O_8			
	PROBABLE	POSSIBLE	SPECULATIVE	TOTAL
VEINS	62,000	120,000	80,000	262,000
VOLCANICS	32,000	325,000	–	357,000
INTRUSIVES	18,000	36,000	40,000	94,000
LIGNITES	16,000	2,400	10,000	28,400
LIMESTONES	15,000	2,500	10,000	27,500
TOTAL (ROUNDED)	143,000	486,000	140,000	769,000

still exists, but it is no longer in the $8 cost category. Similar but less marked reductions occurred in the $10, $15 and $30 reserve categories. During the year, while some 13,000 tons of U_3O_8 were added to reserves, about 12,600 tons were mined and shipped to mills.

For its study of resources, ERDA subdivided potential resources into three categories: probable, possible, and speculative, to reflect the varying nature of the estimates depending upon the specific situation. Probable resources are those contained within favorable trends largely delineated by drilling data within known productive uranium districts. In this situation, favorable geologic characteristics of a formation are known from drilling or outcrop data, and quantitative estimates of potential resources are made by considering the size of the favorable areas and by comparing the geologic characteristics with those present in the areas with ore deposits.

Possible potential resources include those situations that are outside of identified mineral trends but which are in formations and geologic provinces that have been productive. Speculative resources are those estimated to occur in formations or geologic provinces which have not been productive but which, based on the evaluation of available geologic data, are considered to be favorable for the occurrence of uranium deposits. There is inherent uncertainty in these estimates, much more so for the speculative than the probable potential.

4. Prospects for Resolving the Issue

It is expected that a systematic and comprehensive evaluation of all of the conterminous United States and Alaska can be accomplished by 1980. There are no illusions that this evaluation, now in progress, will reveal the ultimate availability of uranium resources in the U.S., but it is expected to make it possible, with some reasonable degree of confidence, to place a practical limit on the uranium that could be discovered and produced from U.S. resources within the $30 category for the balance of the century. The rationale for this expectation is as follows:

1. Some uranium deposits which may exist in fact, but whose existence is not revealed or suggested by the NURE program, may remain undiscovered indefinitely. They will give no "signals" that can be detected or recognized by the exploration techniques developed up to the present time.

2. Exploratory drilling by industry will almost surely be confined to favorable areas, as presently known, or as revealed by the NURE program or as deduced by industry geologists. The sheer magnitude and cost of drilling in other areas, and its inordinately high risk of failure, essentially assures that drilling will not be done in areas for which there are little or no favorable indications.

These considerations suggest that the NURE program can resolve the current issue by about 1980, not because it will have assessed the ultimate resource availability, but rather because it will have provided a basis for establishing a practical upper limit on the cumulative amount of uranium that could be located and produced from relatively high grade ores in the U.S. for many years into the future. This is a consideration which assumes that the NURE program will be reasonably efficient in finding those areas throughout the United States which have favorable or positive indications, and will have, by 1980, greatly reduced the chance that additional favorable areas will remain to be found.

SECTION III F

ADDITIONAL COST-BENEFIT ANALYSIS INFORMATION

INTRODUCTION

The cost-benefit analyses provided in the PFES have received extensive comment by letter (see Section V) and during the Public Hearing held on May 27-28, 1975. The comments were to the effect that the analyses:

a) were too favorable to the LMFBR because they overestimated the potential energy demand; underestimated the capital cost differential; utilized R&D costs that were too low; used introduction dates for the breeder that were too early; and made estimates of uranium resources that were too low and of uranium prices that were too high.

b) were too unfavorable to the LMFBR because they used too high a discount factor; the uranium price and separative work price projections were too low; and estimates of uranium resources were too high.

c) did not adequately treat the cost-benefits of alternative energy systems such as substantial use of solar energy substitution for electric space heating and cooling; greatly expanded use of geothermal energy and expedited development of fusion power.

These issues were all treated in the PFES (Section II of this document) in Sections 11.1 and 11.2.

The Internal Review Board in its Report to the Administrator[1] reviewed the controversy (see Section IV B, pps. IV B-20 to -27) and stated:

"The Board is wary of facile attempts to resolve these areas of controversy, dependent as they are upon future events which are now more or less speculative. With regard to projections of energy demand, it seems prudent to assume a moderate level of growth for planning purposes. This is so not because ERDA is committed to any particular growth scenario, but simply because the penalties for underestimation are likely to be far more severe than those for overestimation. A program can be scrapped if its need does not become actualized. But the long lead times involved in research and development programs and plant construction make it relatively difficult to accelerate efforts which have been held in abeyance pending an unmistakable confirmation of their need.

"With respect to uranium resources, the Board is impressed with the view of Dr. Stauffer that there is no reliable methodology by which extrapolations can be made from known reserves.[2/] Although significant information can and no doubt will be developed in advance of physical exploration, optimism beyond that reflected in the cost-benefit projections may be unwarranted at this time.

"Due to the vagaries of the manufacturing and construction industries, it seems equally perilous to speculate at this time on the capital cost question. We note that the PFES brackets these areas of uncertainty with sensitivity analyses indicating the influence of various assumptions upon the results. Future events will narrow the bands of uncertainty and permit a more reliable verdict on the LMFBR economics.

"In the interim, the Board finds that the PFES is reasonably complete and sufficient for present decisionmaking.

"The assumptions employed as to energy demand, uranium supply and capital costs may eventually prove to be unrealistic and therefore reduce the calculated benefits. On the other hand, it would be risky to underestimate the advantages of the R D & D Program at this time. Indeed, the value of better information seems undisputed, and, as it becomes available, the record should be supplemented and the course of the Program reevaluated.

"The Board believes that while the final verdict on the economic costs and benefits of a commercial LMFBR industry must be left to the utility industry, ERDA must reserve to itself the judgment as to whether the noninternalized environmental costs, balanced against the net economic benefits of a prospective LMFBR industry warrant a continuation of the Program to the point of commercialization. The present record is not deemed to be ripe for this determination."

Recognizing that input data has changed significantly since the analyses presented in the PFES were performed, Section III F has been prepared to provide up-to-date cost-benefit analyses. Section III F.1 provides additional material on the electric energy cost of substituting alternative energy systems for nuclear power. This Section should provide the reader with a grasp of the economic costs

"

2/ Hearing Transcript, pages 399-401."

involved in such substitution and should help permit rational estimates to be made as to the relative cost-benefit ratios of such alternatives. In addition, a revised economic cost-benefit analysis of the LMFBR has been prepared. Since the PFES was published, the basic data which affect the conclusions of the cost-benefit analyses have changed substantially. In particular, estimates of future electrical energy requirements, future enrichment costs, future uranium ore costs, future nuclear plant capital costs and future R&D costs have all changed. These updated factors have been used in revised cost-benefit analyses which are presented in III F.2. Despite the fact that updated data was used, uranium prices continue to increase at a rapid rate since the calculations were made for this revised cost-benefit analysis. The increase has been such that even the high price uranium projection is considered conservative. Hence the LMFBR benefits should be considered low even for this revised study.

11.1S ELECTRIC ENERGY COSTS FOR ALTERNATIVE POWER SUPPLY SCENARIOS

1. INTRODUCTION AND SUMMARY

This section concerns a cost comparison between the U.S. electric power economy being supplied in large part by a combination of solar, geothermal, organic waste and fusion power sources coupled with fossil and nuclear (LWR and HTGR) power sources and a combination of solely fossil and nuclear power sources referred to as "conventional" with LMFBRs included. The solar, geothermal, organic waste and fusion power sources are referred to as "alternative" (new technology) power sources.

Using the same techniques as in the revised LMFBR cost-benefit study, calculations were made for two energy projections, designated as low and base, for the cost comparisons. The low energy projection, 13.8 trillion Kwhr(e) by the year 2020, corresponds to the projection used by Cochran, et al. in the paper "Bypassing the Breeder"[2] and the low energy projection in the revised LMFBR cost-benefit analysis. The base energy projection, 21.9 trillion Kwhr(e) by the year 2020, is similar to the base energy projection utilized in the revised LMFBR cost-benefit analysis. Hence, four cases were calculated with each energy projection having two cases, one with and another without the alternative power sources. The cases without the alternative power sources included the LMFBR. The cases with alternative power sources included only those nuclear plants that were operating, under construction or on order by January 1, 1975.

In "Bypassing the Breeder" Cochran suggested the following scenario for electric energy generation in the year 2020, consisting mainly of alternative energy sources:

Source	Energy
Solar	5.5 trillion kwhr(e)
Geothermal	1.7 trillion kwhr(e)
Fusion	2.2 trillion kwhr(e)
Organic Wastes	0.6 trillion kwhr(e)
"Other Sources" (mainly fossil fuels)	3.8 trillion kwhr(e)
	13.8 trillion kwhr(e)

A projection of alternative capacity commitment was developed to correspond approximately to Cochran's energy scenario. A corresponding projection was developed to apply to the basic energy projection. These capacity projections are shown in Table III F-1. It is noted that the capacity projections for alternative plants

Table III F-1

CAPACITY PROJECTIONS FOR "ALTERNATIVE" PLANTS

Year	Operating Capacity, GW: Geothermal	Solar	Organic Waste	Fusion (CTR)
A. Base Energy Projection				
1980	10	--	6	--
1990	58	2	29	--
2000	228	290	87	--
2010	628	731	89	199
2020	783	1068	89	1309
2025	783	1156	89	1849
B. Low Energy Projection (Cochran Scenario)				
1980	10	--	6	--
1990	43	2	29	--
2000	95	290	88	
2010	164	713	88	177
2020	215	1068	88	587
2025	149	1140	88	772

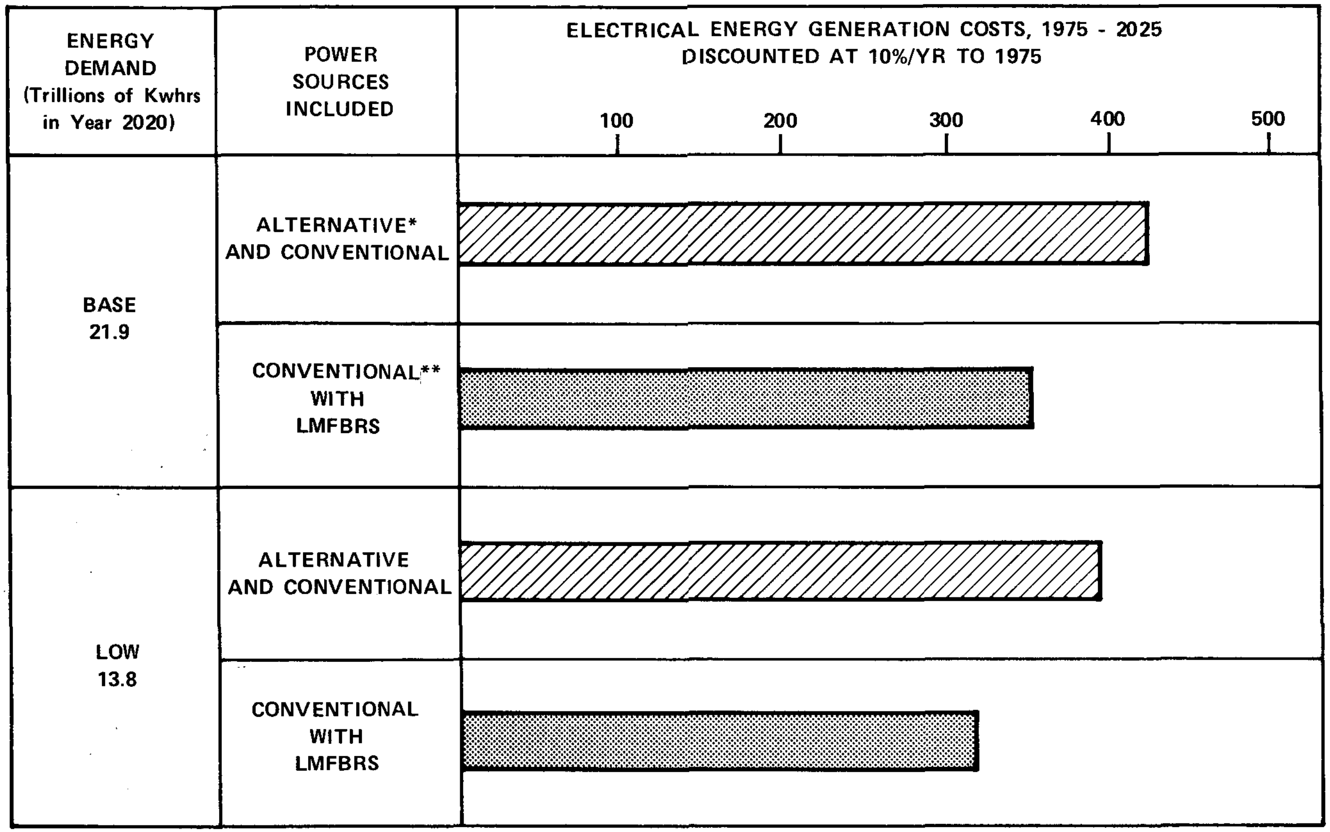
for both energy projections for solar and fusion and the base energy projection for geothermal are much larger than projected by ERDA in 1975. However, these high projections of Cochran were accepted to examine the cost effect of possible utilization of alternative power sources as a full substitute for nuclear.

In the cost calculations all alternative plants were assumed to be base-loaded. Any additional capacity required to meet projected power demands was assumed to be supplied by fossil plants (base-load and load-following plants) except for those nuclear plants now in operation or committed for operation by 1985.

In all cases the "conventional" plants considered were the nuclear power plants described in the revised LMFBR cost-benefit study and the fossil plants (with costs updated to 1975) described in the LMFBR Program Proposed Final Environmental Statement (PFES) cost-benefit study. The treatment of conventional plant utilization differed from that in the revised LMFBR cost-benefit study in that (1) effects of fossil plants were considered, and (2) both base-load and load-following plants were included in the calculations. In other respects cost data and ground rules were selected to conform as closely as possible to those used in the revised LMFBR cost-benefit study.

In each case the total cost of U.S. electric energy generation from 1975 through 2025 was calculated and discounted at 10% per year to 1975. For the two cases involving alternative energy source scenarios, generation costs were obtained which were considerably higher than the corresponding cases assuming conventional sources with the LMFBR. These costs were also considerably above costs of corresponding cases in the revised LMFBR cost-benefit studies, with or without assumed availability of the LMFBR.

In the case of the Cochran (low energy) scenario, the discounted power cost was calculated to be $389 billion; for the corresponding scenario using the base energy projection, costs were calculated at $432 billion. The corresponding costs assuming use of conventional plants were, respectively, $314 billion and $343 billion. The discounted cost penalty associated with the alternative sources is about $89 billion for the base energy projection and about $75 billion for the low energy projection. The costs are shown in Figure F-1.



* Alternatives Include Solar, Geothermal, Organic Waste and Fusion

**Conventional Includes Fossil (Coal) and Nuclear (LWR and HTGR)

POWER COST SUMMARY: ALTERNATIVE VERSUS CONVENTIONAL POWER SYSTEMS

Figure III F-1

2. "ALTERNATIVE" PLANTS

Four categories of alternative plants were considered in the study, with characteristics as described below. Plants committed prior to 1990 were assumed to be rated at 1300 MWe capacity; plants installed in or after 1990 were taken as 2000 MWe.

Economic data for these plants was for the most part expressed in 1974 dollars. To convert these data to 1975 dollars in conformance with the revised LMFBR cost-benefit study, escalation factors of 9.5% were applied to capital costs, and of 6% to operating and maintenance costs.

A. Geothermal plants were assumed to be introduced in the late 1970's. For the low energy (Cochran) scenario, they were assumed to increase in capacity to 215 GW in 2020, dropping to 148 GW in 2025. For the case considering the base energy projection, capacity was assumed to increase to about 783 GW in the 2020-2025 period. The projections for the "low" energy scenario are in general agreement with the capacity goals given in "The Nation's Energy Future."[3]

Capital and operating costs of the geothermal plants were based on estimates in the Project Independence Blueprint.[4] A unit capital cost of \$712/KWe in 1974 dollars was assumed; this is the mid-range value of \$562-862/KWe given in the Blueprint, and assumes the major source of geothermal energy derives from hydrothermal, liquid-dominated reservoirs. No scaling of unit capital costs was assumed for different capacity ratings. Cost scaling does not appear appropriate for these plants because of probable costs of steam collection systems for large units. The capital costs were escalated to \$780/kWe for expression in 1975 dollars.

Operating costs were set at 2 mills/kwhr(e), (2.12 mills/kwhr(e) in 1975 dollars) based again on information from the Project Independence Blueprint. Based on plants operating at 100% capacity factor, an arbitrary division of 2/3 fixed costs and 1/3 variable costs was assumed. (See Table III F-3 for definitions of fixed and variable costs.)

Technical, economic, and environmental aspects of the use of geothermal energy are discussed in detail in Section 6A.4 of the PFES. The assumptions of capacities and costs used herein are in agreement with the PFES discussion.

B. Solar energy converters were assumed to be introduced in the early 1990's, increasing in capacity to about 890 GW in 2020. This penetration is greater than can be inferred from the NSF/NASA Solar Energy Panel Report,[5] but is in line with the Cochran scenario.

The solar energy contribution would presumably consist of a mix of thermal-conversion, photo-voltaic, ocean-thermal, and wind energy systems, but with thermal-conversion and photo-voltaic being the dominant solar conversion systems. Cost estimates for solar-to-electric conversion are highly uncertain because the technology is not well developed. Estimates by Subpanel IX,[6] which provided input data to the report on "The Nation's Energy Future," indicates costs of $1300-2500/KWe (average) for thermal-conversion and photo-voltaic systems. This estimate does not account for sufficient energy storage to allow solar energy plants to operate as firm power sources. If sufficient energy storage were included, the above estimates would increase by several hundred dollars per kilowatt. Nevertheless, for purposes of this study, the optimistic assumption was made that solar conversion plants with sufficient energy storage to permit base load operation could be constructed for $1500/KWe (average) -- or, in 1975 dollars, $1643/KWe (average). This cost, derived from the above sources, some of which are relatively old are, however, in the range of new cost estimates under preparation by ERDA.

Annual operating and maintenance costs were taken as 2% of the capital investment. These costs agree closely with the 3 mills/kwhr(e) estimated by EPRI[7] as O & M costs for solar plants. O & M costs were arbitrarily divided as 5/6 fixed costs, 1/6 variable costs (based on 100% plant factor).

Aspects of solar energy utilization are discussed in detail in Section 6A.5 of the PFES.

C. Organic waste burners were assumed to first come on line in the mid-1970's, to penetrate to a capacity of 78 GW by the year 2000, and to hold at that capacity through the year 2025. The on-line capacity of these plants was assumed to be limited by the availability of collected urban organic wastes, as discussed on pages 6A.6-13 and 11.1-21 of the PFES. No attempt was made to factor in bio-mass contributions from aquacultone and forestry residues. Energy generation from this source agrees with Cochran's proposed value in "Bypassing the Breeder."

Organic waste-burning plants were assumed to have capital and operating costs comparable to those of a coal-burning power plant with no desulfurization equipment. Capital costs were estimated at $291/KWe ($319 in 1975) for a 1300 MWe plant, and $265/KWe ($290) for a 2000 MWe plant. Fixed O & M costs, for 1300 and 2000 MWe plants were estimated at $6.6 and $8.8 million per year in 1975 dollars and variable O & M costs (100% plant factor) were $10.5 and $14.1 million per year in 1975 dollars. The capital and O & M costs for these plants were furnished by Holifield National Laboratory using the same methods as were used for plant capital and operating costs provided for the PFES.

Organic wastes used as fuel in these plants were assumed to be available free of charge. However, an addition of 10% oil as supplemental fuel was assumed to be needed to maintain good combustion. At $11/bbl and an assumed heat rate of 10,000 btu/kwhr(e), this resulted in a net fuel cost of 1.87 mills/kwhr(e).

D. Fusion plants were assumed to become available shortly after the year 2000 and to penetrate the power supply rapidly; about 590 GWe were assumed to be on line by the year 2020 for the low energy projection. Energy generation from these plants in the year 2020 is somewhat greater than that suggested by Cochran.

Since the scientific feasibility of fusion reactors has yet to be demonstrated, there is little basis for estimating capital and operating costs. A preliminary estimate by Kulcinski and Conn of the University of Wisconsin[8] indicated that a 1500 MWe CTR might cost $900-1000/KWe. An AEC study (WASH-1239)[9] estimated the cost of a CTR to be about $500/KWe. For purposes of this study, fusion reactors were assumed to produce power at a cost equivalent to the average power cost of nuclear plants over the span from the years 2000 to 2020, calculated for Case 3 (the base LMFBR case) of the PFES cost-benefit study. Capital and operating costs (Tables III F-2 and III F-3) were chosen consistent with those power costs. Net fuel costs were assumed to be zero. It should be noted that the assumed capital cost of $445/KWe is somewhat lower than the estimates cited above. Escalation of capital and O & M costs to 1975 dollars resulted in a CTR power cost equivalent to that of the LMFBR.

Consideration of the use of CTR systems is discussed in Section 6A.1.6 of the PFES.

Capital costs assumed for the alternative plants are summarized in Table III F-2, operating and maintenance costs are shown in Table III F-3.

TABLE III F-2

CAPITAL COSTS ASSUMED FOR CONVENTIONAL AND ALTERNATIVE PLANTS
(Costs in mid-1974 dollars)

Plant Type	1300 MWe		2000 MWe	
	$/KWe	$$10^6$	$/KWe	$$10^6$
LWR	460	598	(none considered)	
HTGR	460	598	(none considered)	
LMFBR				
1993	560	728	--	--
2000	--	--	506	1012
2006	--	--	460	920
Fossil (coal)	380	494	346	692
Geothermal	780	1014	780	1560
Solar	--	--	1643	3286
Organic Waste	319	415	290	580
Fusion (CTR)	--	--	487	974

TABLE III F-3

OPERATING AND MAINTENANCE COSTS ASSUMED FOR CONVENTIONAL AND ALTERNATIVE PLANTS
(Costs in millions of mid-1974 dollars per year)

Plant	1300 MWe		2000 MWe	
	Fixed*	Variable**	Fixed*	Variable**
LWR	4.77	2.49	(none considered)	
HTGR	4.74	2.49	(none considered)	
LMFBR	5.30	3.0	6.50	3.68
Fossil (coal)	7.51	16.87	10.15	25.99
Geothermal	12.23	7.04	18.72	10.82
Solar	--	--	53.19	10.5
Organic Waste	6.6	--	8.83	14.07
Fusion (CTR)	--	--	7.45	2.57

*Fixed costs are for staff, fixed maintenance, fees, and administration.
**Variable costs are for variable maintenance, supplies, and miscellaneous. For coal plants they also include limestone, ash, and slurry disposal. Variable O&M costs are based on a 100% capacity factor.

3. RESULTS OF CALCULATIONS

Levelized power costs were calculated for the alternative plants, assuming these plants had the same base-load characteristics assumed for base-loaded plants in the revised LMFBR cost-benefit study. Each individual plant was assumed to reach 72% annual capacity factor by the end of the second year following startup, and to remain at 72% through its 15th year of life; thereafter the capacity factor decreased linearly to 50% at end of its 30-year life. The average lifetime capacity factor with this assumption is 65.9%.

A. Plant Power Cost Comparisons

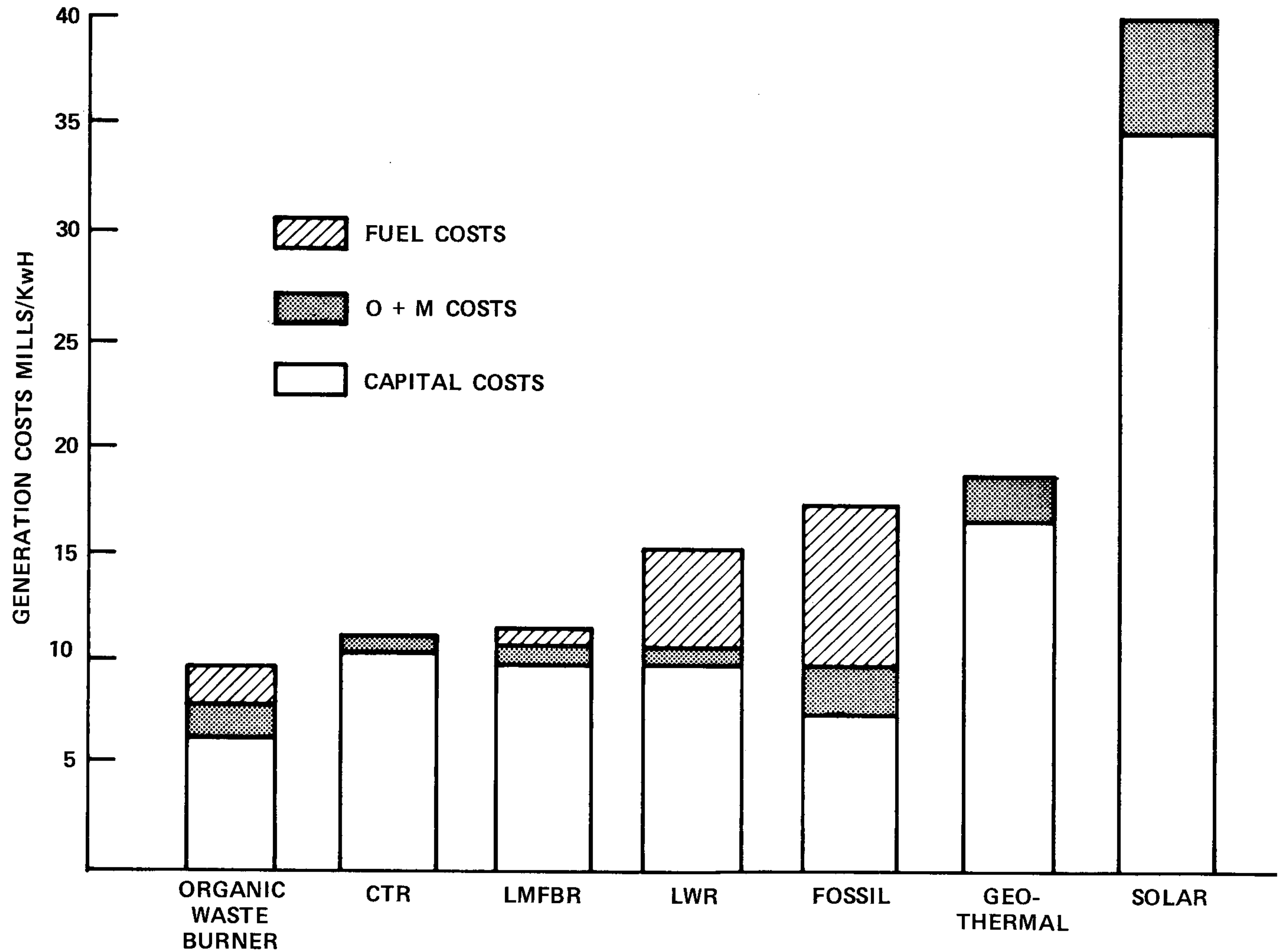
The calculated power costs are shown for post-1990 (2000 MWe) plants, in Figure III F-2. Also shown on the same figure are typical costs for LWRs (using $35/lb uranium), LMFBRs, and coal-fired plants (using 83¢/MBTU fuel). Based on available estimates for costs of building and operating the alternative plants, only the capacity-limited organic waste converters and the advanced CTR system -- which are not projected to attain significant on-line capacity until the 2010-2020 area -- are seen to be cost-competitive with conventional power plants considered in the PFES cost-benefit study.

B. Power System Composition: Cases Considered

Calculations concerned two electrical projections, as previously mentioned: the base and low projections for the revised cost-benefit study, building to 21.9 trillion kwhr(e) and 13.8 trillion kwhr(e) respectively in the year 2020. For each energy projection, two cases with and without alternative power sources were calculated which considered the contributions to electric energy supplied by both base-loaded and load-follower plants. Details of the method of calculation, and the assumptions involved, are provided in Section 11 of the PFES, and in the description of the revised LMFBR cost-benefit study included in this supplement.

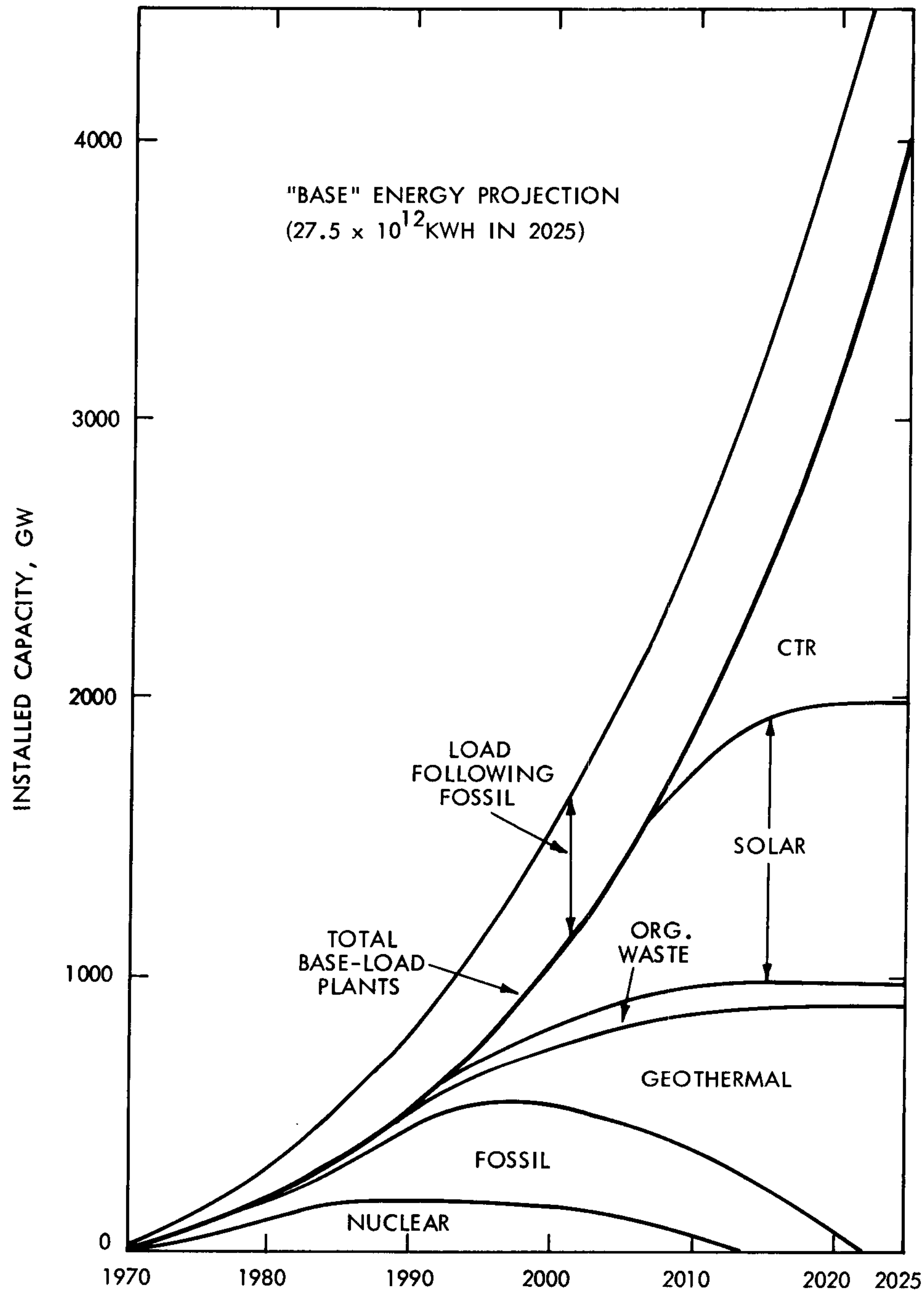
Figure III F-3 indicates the mix of plant types for the case involving the alternative power sources with the base energy projection; the corresponding mix for the low energy projection is shown in Figure III F-4.

Results of the alternative case calculations, which were summarized in Figure III F-1, are shown in more detail in Table III F-4, with comparable conventional plant cases.

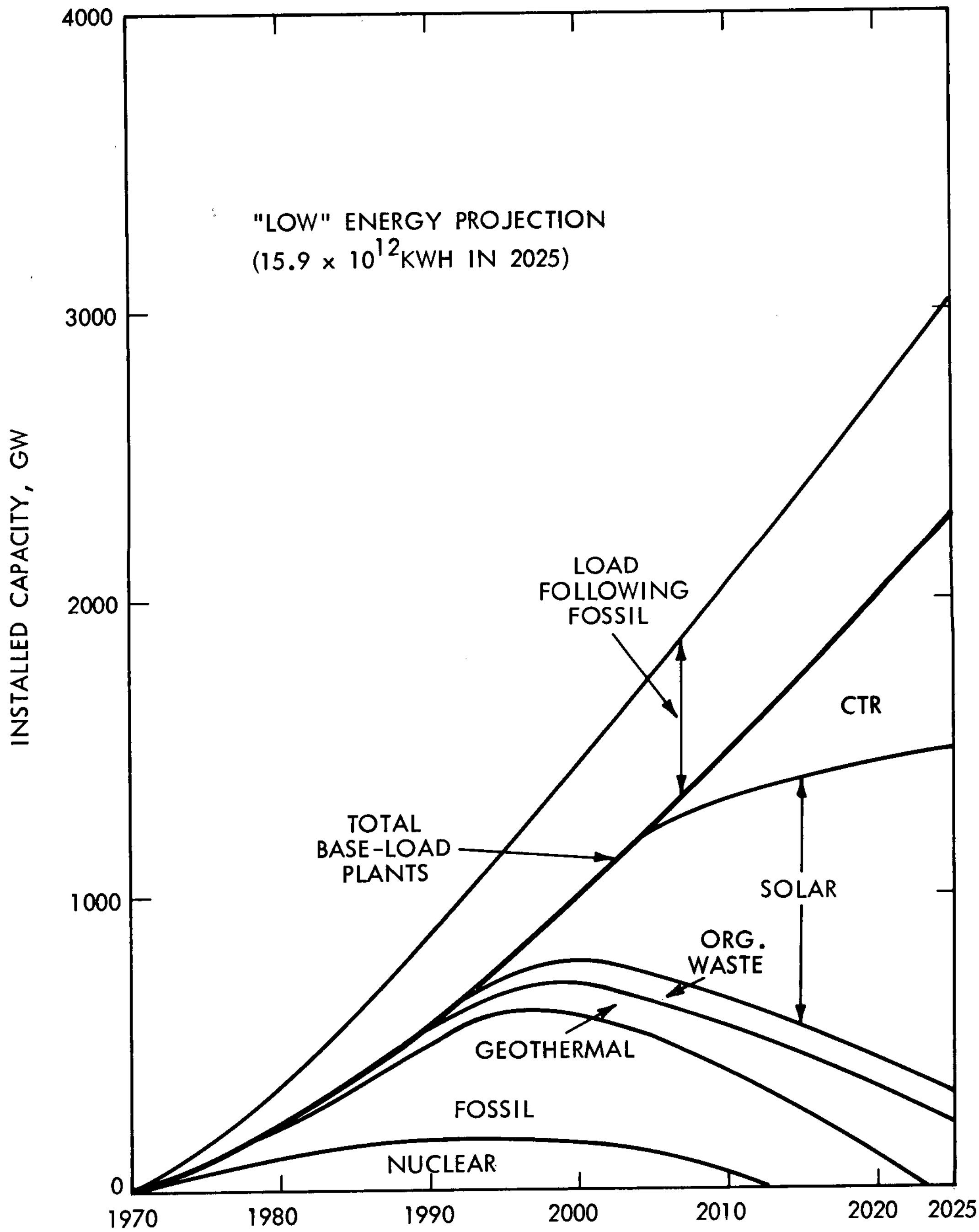


UNIT POWER COST COMPARISON: ALTERNATIVE VERSUS CONVENTIONAL POWER PLANTS

Figure III F-2



POWER SYSTEM COMPOSITION WITH
ALTERNATIVE POWER SOURCES & BASE ENERGY PROJECTION
(PRE-1970 PLANTS EXCLUDED)
<u>Figure III F-3</u>



POWER SYSTEM COMPOSITION WITH
ALTERNATIVE POWER SOURCES & LOW ENERGY PROJECTION
(PRE-1970 PLANTS EXCLUDED)

<u>Figure III F-4</u>

Case X-1, a base-energy alternative power source case considering both base-loaded and load-follower plants, is directly comparable to Case 1, which considered competition among nuclear and fossil plants under similar conditions. Case 1, in turn, is similar to the base case for the revised LMFBR cost-benefit study but includes load-follower plants and allows competition among nuclear and fossil plant types.

Cases X-2 and 2 are the corresponding cases for the low energy projection. Case X-2 is the Cochran scenario.

Cases 3 and 4 were run to check the validity of comparison of the alternative cases with those considering only conventional plants. In these cases, conventional plants were allowed to compete economically with the alternate sources. In these cases, the only alternative plants selected for introduction were the organic waste burner and, late in the study, the CTR generator. Cost differences from all conventional cases were not significant.

The alternative cases, on the other hand, indicated electric power costs 25% to 30% higher than for the corresponding cases including only conventional plants. These cost increases were consistent for both energy projections, and discounted cost tabulations taken to intermediate years show a continuous divergence of costs from the date of alternative sources introduction.

With "negative benefits" of this magnitude, it is difficult to conceive that the alternative power sources will be incorporated in large quantities into the U.S. electrical power economy unless costs of the developed plants are markedly different than projected in this analysis.

Table III F-4

POWER COST COMPARISONS: ALTERNATIVE VS. CONVENTIONAL SYSTEMS

(Costs in billions of dollars (1975-2025) discounted at 10% to 1975)

Case No.	Energy Demand	Plants Considered	Costs	Compared With Case	Cost Difference
1	Base	Conventional	343.2	--	
X1	Base	New Technology	432.0	1	88.8
2	Low	Conventional	314.0	--	
X2*	Low	New Technology	388.6	2	74.6
3	Base	All	339.9	1	-3.3
4	Low	All	311.5	2	-2.5

*Case X2 is the Cochran scenario

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11.2S A REVISED ECONOMIC COST-BENEFIT ANALYSIS OF THE LIQUID METAL FAST BREEDER REACTOR PROGRAM

1. INTRODUCTION

In December 1974, the U.S. Atomic Energy Commission issued the Proposed Final Environmental Statement (PFES) for the Liquid Metal Fast Breeder Reactor (LMFBR) Program.[1] This comprehensive statement, contained an analysis of the probable development of the nuclear power economy to the year 2020 (see Section 11 of the PFES). In the period since that analysis was prepared, the basic data which affect the relative economic competitiveness of the LMFBR have changed. In particular, estimates of future electrical energy requirements, future uranium enrichment costs, future uranium ore costs, future nuclear plant capital costs and future R&D costs have all changed. In view of this, the nuclear energy economy has been reanalyzed to more accurately determine the costs and benefits role of the Liquid Metal Fast Breeder Reactor. The entire analysis was also placed in perspective by viewing the nuclear energy economy in terms of the total U.S. energy situation over the next fifty years.

Numerous studies and statements analyzing and discussing the role of the LMFBR in the nuclear energy economy have been published[2-13] in the past twelve months. It is hoped that a comprehensive analysis utilizing the most recent data will clarify the principal issues regarding the economic feasibility of the LMFBR.

In this study, the new data was utilized in a model of the nuclear power economy based on the linear programming technique in an analogous manner to the analysis performed in the PFES. The objective function of the linear program was designed to minimize the cost of energy over the planning horizon. This method of analysis is capable of providing straightforward conclusions about the economic feasibility of the LMFBR. The analysis showed that society will gain substantially by the development of the LMFBR.

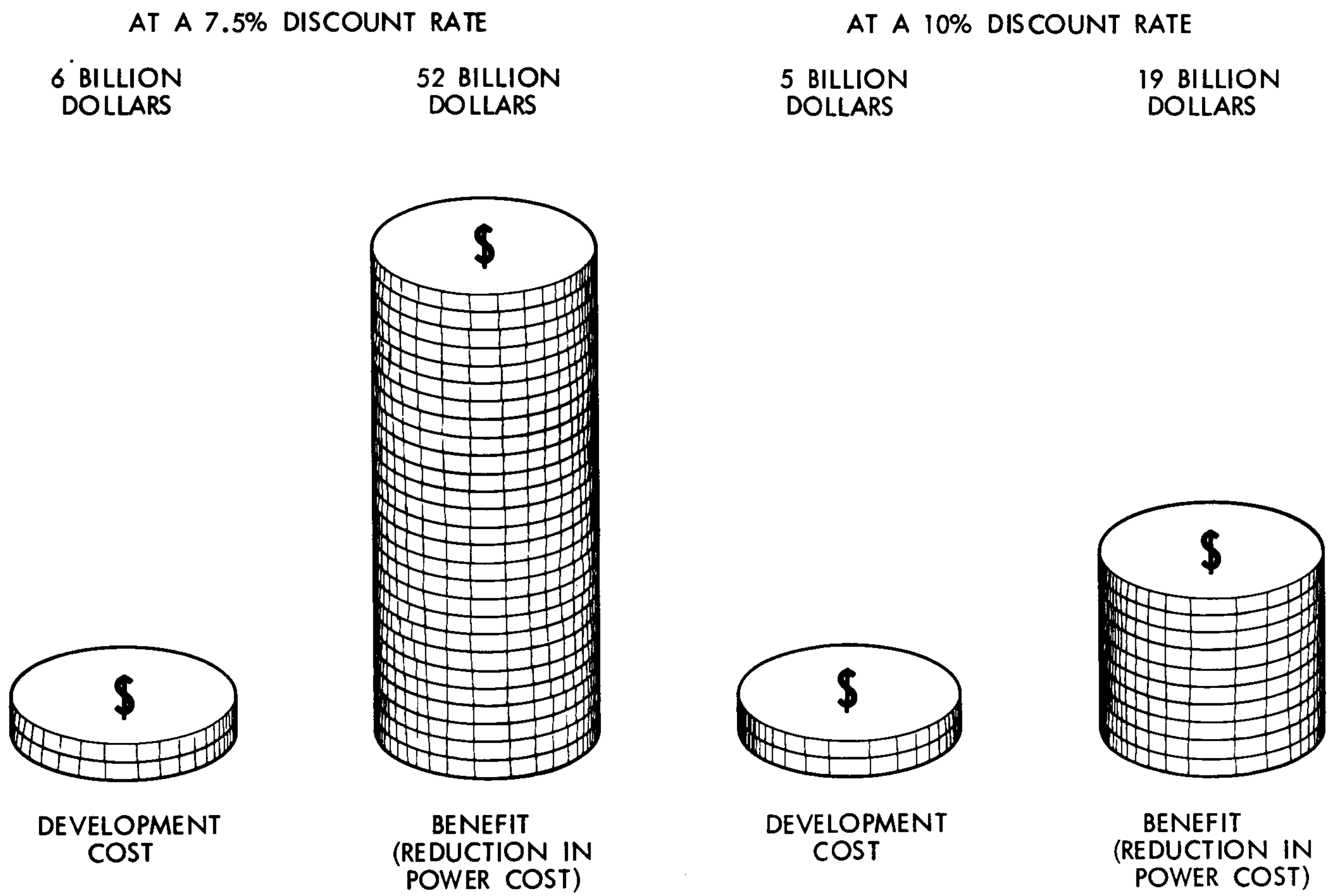
2. SUMMARY OF RESULTS

The dollar benefit and the development cost associated with the introduction of the LMFBR are shown in Figure III F-5 for a 1993 LMFBR introduction for base assumptions. The benefit is simply the reduction in total power cost over the planning horizon from 1975 to 2025 obtained by introducing the LMFBR, with future costs properly discounted using present value analysis. With a 1993 LMFBR introduction, the development cost* of the LMFBR program is approximately 6 billion dollars while the benefit is 52 billion dollars, where both values are discounted at a rate of 7.5%. When discounted at a rate of 10%, the development cost* is approximately 5 billion dollars while the benefit is 19 billion dollars. In either case, the benefit is substantially greater than the development cost. The development cost is relatively insensitive to the discount rate since this cost is incurred early in the planning period. The benefit, on the other hand, is accrued in the latter part of the period, and hence is very sensitive to the discount rate. An indication of the sensitivity of the benefits to the discount rate can be obtained by noting that the benefit would be about one trillion dollars at a zero-discount rate. The undiscounted cost of electric energy is reduced by about 85 billion dollars per year in the year 2020 alone.

The benefit is due primarily to the lower nuclear fuel cost obtained by introducing the LMFBR--in particular, by the reduction in the requirements for uranium ore and separative work. These reductions are illustrated in Figure III F-6. Without the LMFBR, the cumulative U_3O_8 requirements to the year 2025 is 5.5 million tons, while with the LMFBR, the cumulative U_3O_8 requirement is 3.0 million tons. Furthermore, without the LMFBR, U_3O_8 will continue to be mined at an ever increasing rate, while with the LMFBR, the annual ore requirement becomes insignificant after the year 2025.

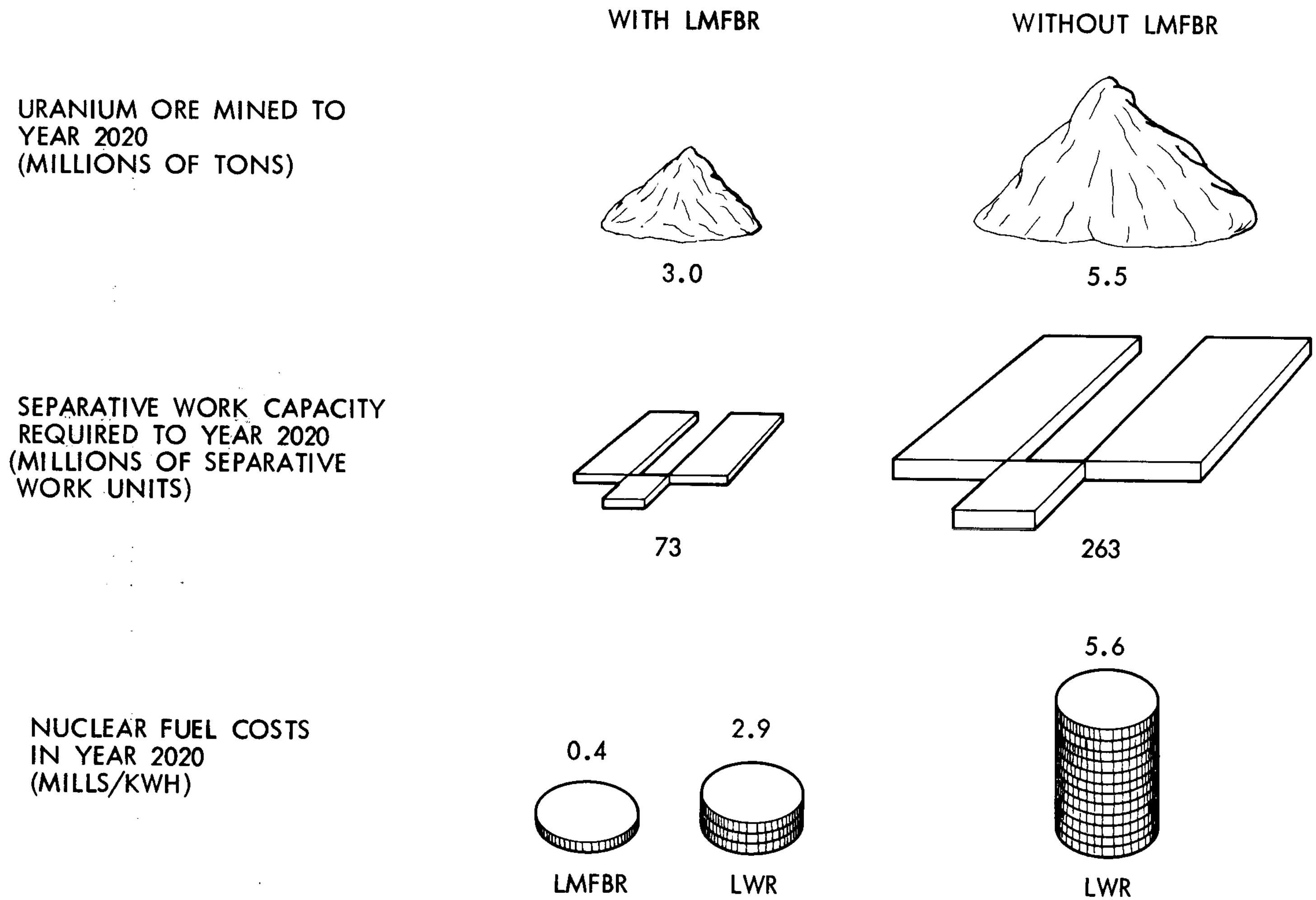
Separative work requirements are also shown in Figure III F-6. Without the LMFBR, an annual separative work capacity of 263 million separative work units (SWU) per year will be required in the year 2025, while with the LMFBR, the maximum separative work requirement will be only 73 million SWU/year. It is worthwhile to mention that the current separative work capacity in the U.S. is only 17 million SWU/year. Without the LMFBR, separative work requirements continue to increase with time, with the LMFBR, the maximum annual separative work requirement of 73 million SWU/year is obtained in the year 2005, and separative work requirements decrease continuously beyond that time. The time dependence of the annual separative work requirement and the cumulative U_3O_8 requirement are shown in Figure III F-7.

*The development costs do not include residual construction costs for the early LMFBRs which may be required to bring them into economic parity with LWR's in that time frame. See Section I.3 discussion on capital costs.



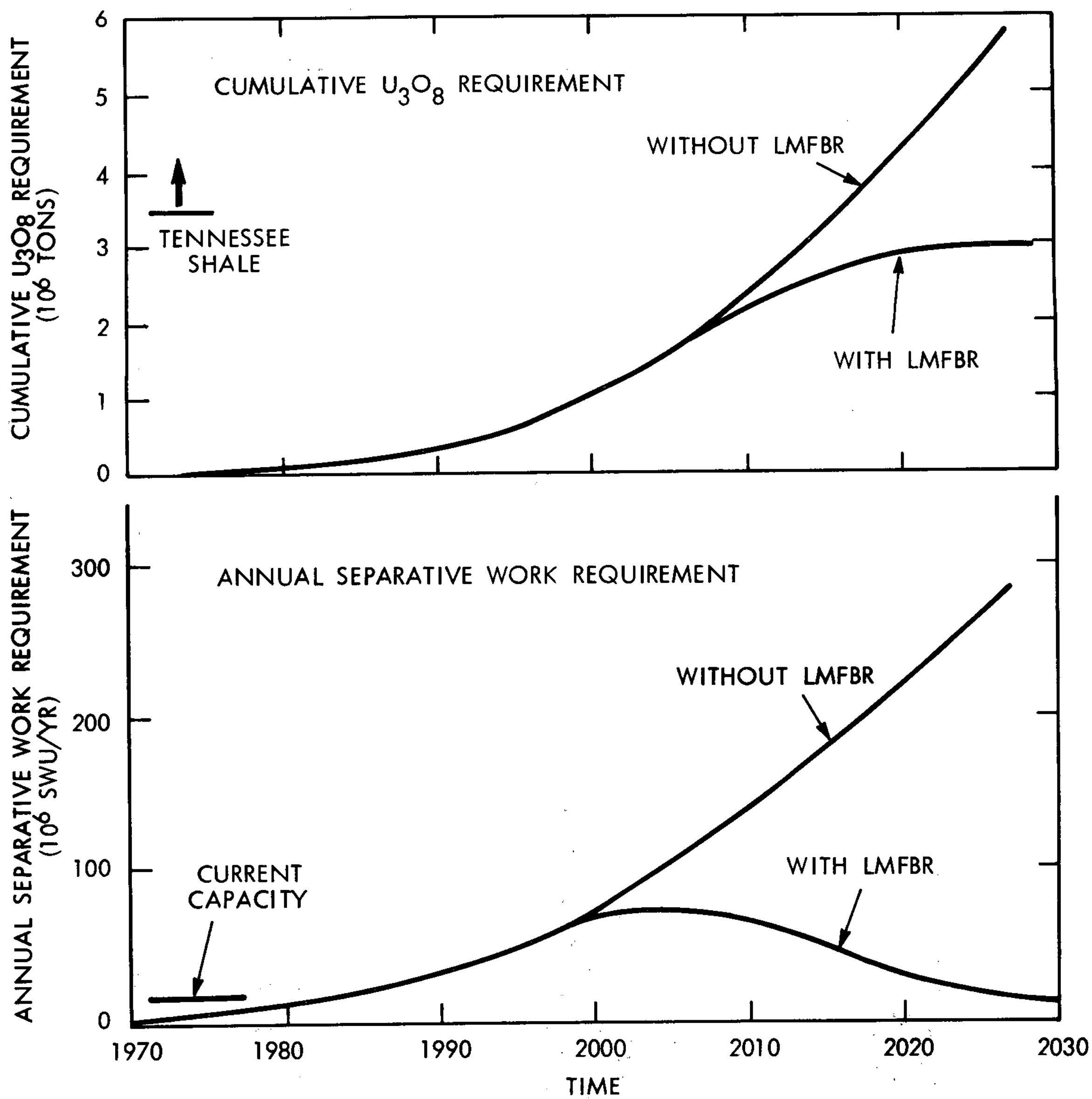
DOLLAR BENEFITS FROM THE LMFBR WITH A 1993 INTRODUCTION

Figure III F-5



INTERPRETATION OF LMFBR BENEFITS WITH A 1993 INTRODUCTION

Figure III F-6



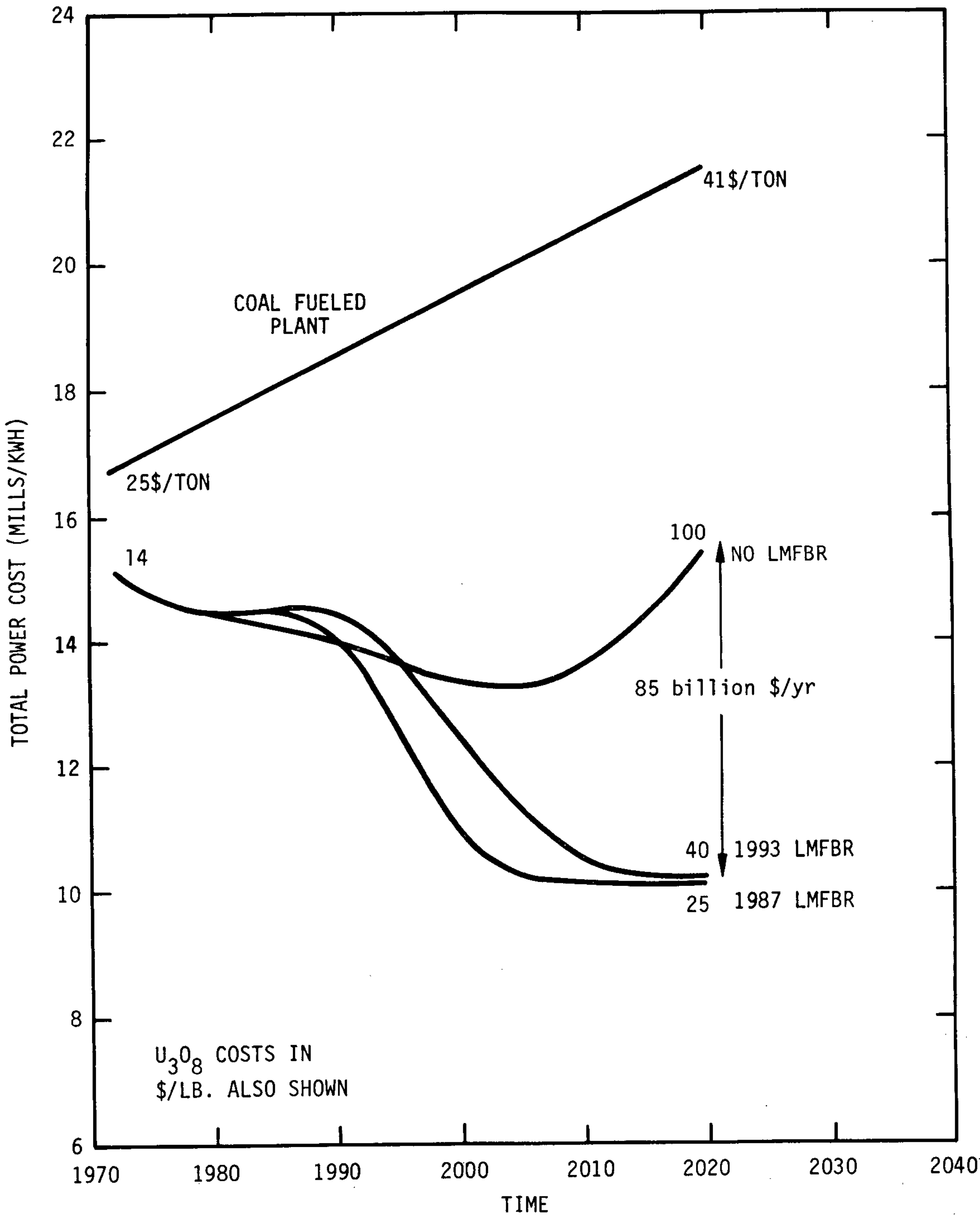
TIME DEPENDENCE OF SEPARATIVE WORK AND CUMULATIVE ORE REQUIREMENTS WITH A 1993 LMFBR INTRODUCTION

Figure III F-7

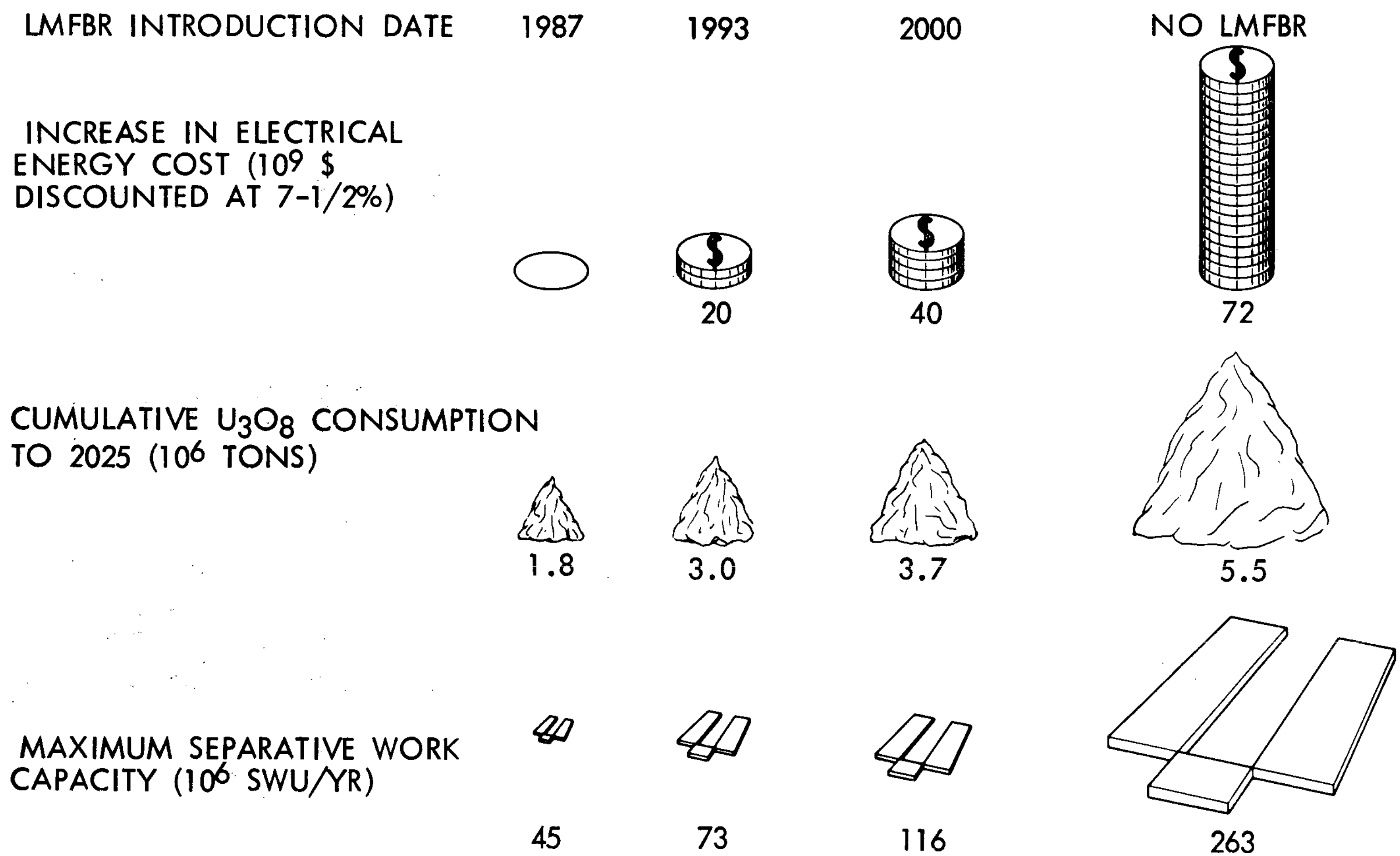
Finally, nuclear fuel costs in the year 2025 are shown in Figure III F-6. Without the LMFBR, the weighted-mean fuel cycle cost for the LWR will increase to 5.6 mills/kwhr(e), while the fuel cycle cost for a uranium-fueled LWR will increase to 8.6 mills/kwhr(e) in 2025. The weighted-mean fuel cycle cost is lower because it includes the effect of plutonium recycle. Throughout this study, plutonium recycle was assumed to be introduced in 1981. Currently, nuclear fuel costs are about 2.8 mills/kwh for a uranium-fueled LWR. Note that the price increases discussed above are real-i.e., exclusive of inflation. With the LMFBR, on the other hand, the weighted mean LWR fuel cycle cost will be stabilized at about 2.9 mills/kwhr(e), while the LMFBR fuel cycle cost will be about 0.4 mills/kwhr(e). Indeed, it is just this difference in fuel cycle costs that is directly responsible for the LMFBR benefits.

The time dependence of the total power costs in the nuclear industry is shown in Figure III F-8. For comparison, the total power cost of a coal-fired plant is also shown. The cost of coal was assumed to be $25/ton in 1975, and coal was assumed to experience a real price increase of 1%/year thereafter. As a consequence, the total power cost for a coal-fueled plant is about 17 mills/kwhr(e) in 1975, and this increases to about 22 mills/kwhr(e) in 2025. Nuclear power costs, on the other hand, decrease as the nuclear industry matures, i.e., as plutonium recycle is introduced, and as unit costs for reactor construction, fuel fabrication, and fuel reprocessing decrease. However, without the LMFBR, nuclear power costs ultimately begin to increase as the industry is forced to mine the lower grade uranium ores. In the year 2020, nuclear power costs for an LWR-HTGR economy with plutonium and U^{233} recycle are rising at the real rate of 1 mill/kwhr(e) every 5 years. Without plutonium and U^{233} recycle, nuclear power costs in the year 2020 will be several mills/kwh higher and will be rising faster. With the LMFBR, the supply of plutonium increases with time, and as a consequence, nuclear power costs fall quite rapidly around the year 2000 after an initial rise in the 1980s due to rising U_3O_8 prices. Nuclear power costs remain constant thereafter since the basic fuel for the nuclear industry is an increasing supply of plutonium, rather than a diminishing supply of U_3O_8.

The effect of a delay in the LMFBR program is shown in Figure III F-9. Note that the discounted (7.5%) electrical energy cost to the nation increases at the rate of about 3 billion dollars per year of delay. Note also that a delay in the introduction date for the LMFBR beyond 1993 will require over 3 million tons of U_3O_8 to be mined. As a consequence, a delay substantially past 1993 will require that the low-grade Tennessee shales be mined. Finally, note that separative work



AVERAGE U.S. NUCLEAR POWER COSTS (1975-2025)
REFERENCE CASE
Figure III F-8



EFFECT OF A DELAY IN THE LMFBR PROGRAM

Figure III F-9

requirements increase by about 5 million SWU/year per year of delay. This almost staggering increase in the required enrichment capacity may be the most compelling argument for the early development of the LMFBR.

A nuclear industry growth pattern that might be considered typical of those obtained in this study is shown in Figure III F-10. This figure shows the reactor construction rate as a function of time throughout the planning horizon. Note that the LWR is the primary power plant through the 1980's and into the 1990's. However, the LMFBR is being built at an ever increasing rate in the late 1990's, and it becomes the predominant power plant after the year 2000. An LMFBR without a blanket, i.e., a plutonium burner, emerges in the decade following the year 2010, and consumes the surplus plutonium from the LMFBR's.

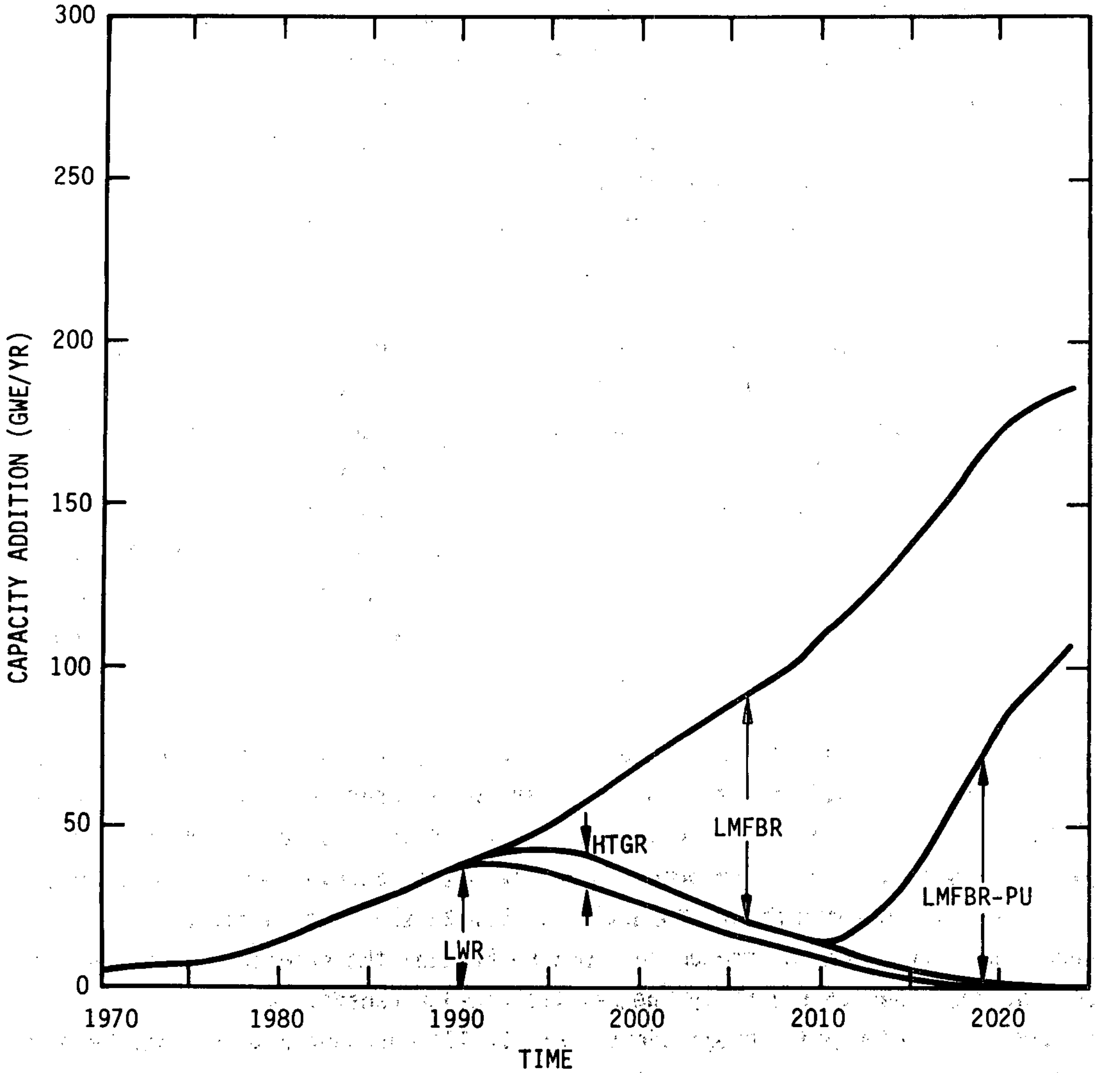
The number of LMFBR's constructed prior to the year 2000 as a function of the LMFBR introduction date is shown in Table III F-5. As the table shows, the LMFBR--if introduced early--can contribute significantly toward meeting the demand for energy in the U.S. in the year 2000. If introduced in 1987, the LMFBR could supply 1.9 trillion kwhr of electricity, and could also reduce the rate of consumption of depletable fuel supplies by 16 quads*/year in the year 2000. An energy source, as defined in A National Plan for Energy Research, Development, and Demonstration,[41] will have a moderate impact if it can supply between 0 and 4.5 quads/year in the year 2000. Likewise, an energy source will have a substantial impact if it can supply between 4.5 and 9.0 quads/year in the year 2000, and it will have a major impact if it can supply more than 9.0 quads/year. Thus, the LMFBR--if introduced early--would have a major impact on the U.S. energy situation in the year 2000.

Table III F-5

ENERGY CONTRIBUTION OF THE LMFBR IN THE YEAR 2000

	Introduction Date		
	1987	1993	2000
LMFBR Installed Capacity in 2000 - Gwe	308	76	0
LMFBR Fraction of Installed Nuclear Capacity in 2000	0.34	0.08	0.00
Electrical Energy Production Rate by LMFBR's in 2000 (10^{12} kwh)	1.9	0.5	0.0
Thermal Energy Production Rate by LMFBR's in 2000 (quads/yr)	16	4	0

*A quad is equal to 10^{15} BTUs.



U.S. NUCLEAR POWER GROWTH PATTERN

REFERENCE CASE - 1993 LMFBR

Figure III F-10

Also, as in the PFES LMFBR cost-benefit study, calculations were made to test the combined effects of coincident changing of two or more of the following major parameters; energy demand projection, LMFBR capital cost differential, LMFBR introduction date and uranium price projections.

Introduction of the breeder in year 1987 results in only one case where the discounted benefits are below estimated development costs. This occurs at the 10% discount rate when the uranium price projections are low, the energy demand is low, and the LMFBR capital cost is high. The 10% discounted benefits for this case are about 1 billion less than the projected discounted development costs. However, at a 7.5% discount rate the breeder benefits for this case are about twice the discounted projected breeder development costs. For the combination of high uranium prices, high energy demand projection and base LMFBR costs the breeder benefits are about $150 billion. Breeder benefits are many times breeder development costs for most cases.

When the breeder is introduced in 1993, there are a few cases where the benefits are about equal to the development costs and they are associated with high capital costs and low energy demand, using the 7.5% discount rate. The cases with either base assumptions or with conditions that induce greater breeder benefits than with the base assumptions have discounted breeder benefits that are many times the discounted development costs. The discounted breeder benefits range up to about $98 billion. At the 10% discount rate the discounted breeder benefits are less than the discounted breeder development costs when the energy demand projection is low <u>and</u> the LMFBR capital cost is high.

It is only with introduction of the breeder in the year 2000 that there are cases where the breeder benefits are much less than development costs at a discount rate of 7.5%. It again requires the energy demand projection to be low and the LMFBR capital costs to be high. The benefits are less than development costs for both the base and low uranium price projections. Due to the late introduction of the breeder the difference in uranium consumption between the breeder and no breeder cases has decreased considerably, hence, the breeder benefits are much less sensitive to uranium price projections. At the 10% discount rate the net benefits for year 2000 introduction are negative for five of the eighteen cases reported. One case is associated with base LMFBR capital costs and low energy demand projections. The other cases are all associated with high LMFBR capital costs and either low energy demand and low uranium price projections. Even with a year 2000 LMFBR there are many cases where the discounted benefits are many times the discounted breeder development costs. The benefits range up to about $57 billion and for base assumptions (other than year of introduction) they are $32 billion and $12 billion for 7.5% and 10% discount rates respectively.

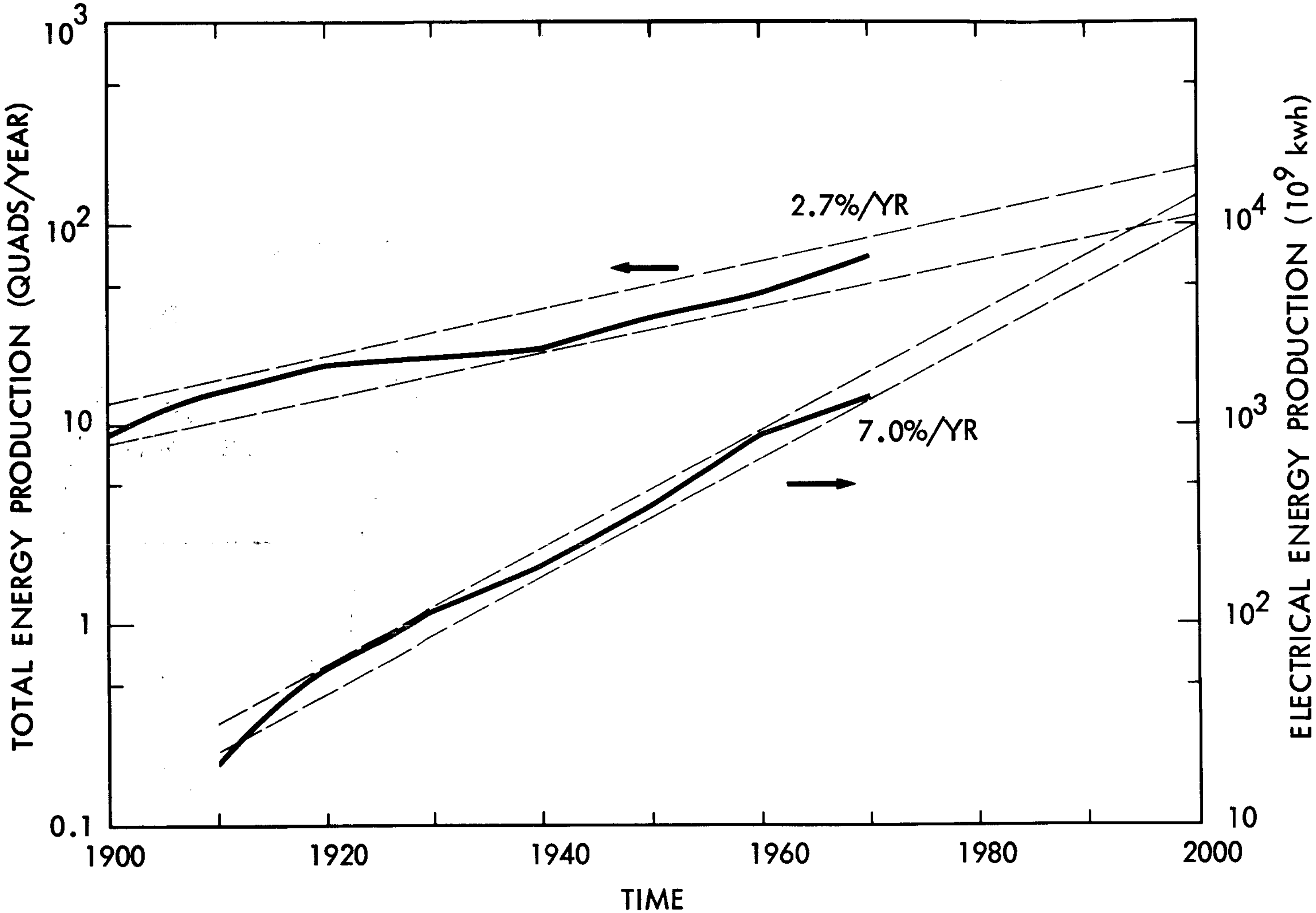
Since the publication of the PFES there has been a large increase in the market place price for uranium and there is no indication of a leveling off in uranium prices. Prices of $25 to $40 per pound of U_3O_8 are the most recent (Oct. 1975) quotes for near term deliveries. These prices are not attained in the base projection of uranium prices in this revised study until after the turn of the century and only shortly before the turn of the century for the high uranium price projection. Hence, if uranium prices were adjusted to more accurately reflect todays uranium prices the benefits would improve for all cases.

3. THE U.S. ENERGY SITUATION

Let us first consider the historical energy production trends in the U.S., as shown in Figure III F-11. It can be seen that total U.S. energy production has grown at the remarkably constant rate of about 2.7%/year over the past 75 years. Likewise, electrical energy production has grown at the remarkably constant rate of about 7.0%/year over the past 55 years. The fact that electrical energy is growing at over twice the rate of total energy is due simply to the substitution of one form of energy for another. The means by which this energy was produced, i.e., the production by primary source, is shown in Figure III F-12. As the figure shows, natural gas and oil produced 76% of the total energy and 33% of the electrical energy in the U.S. in 1974.

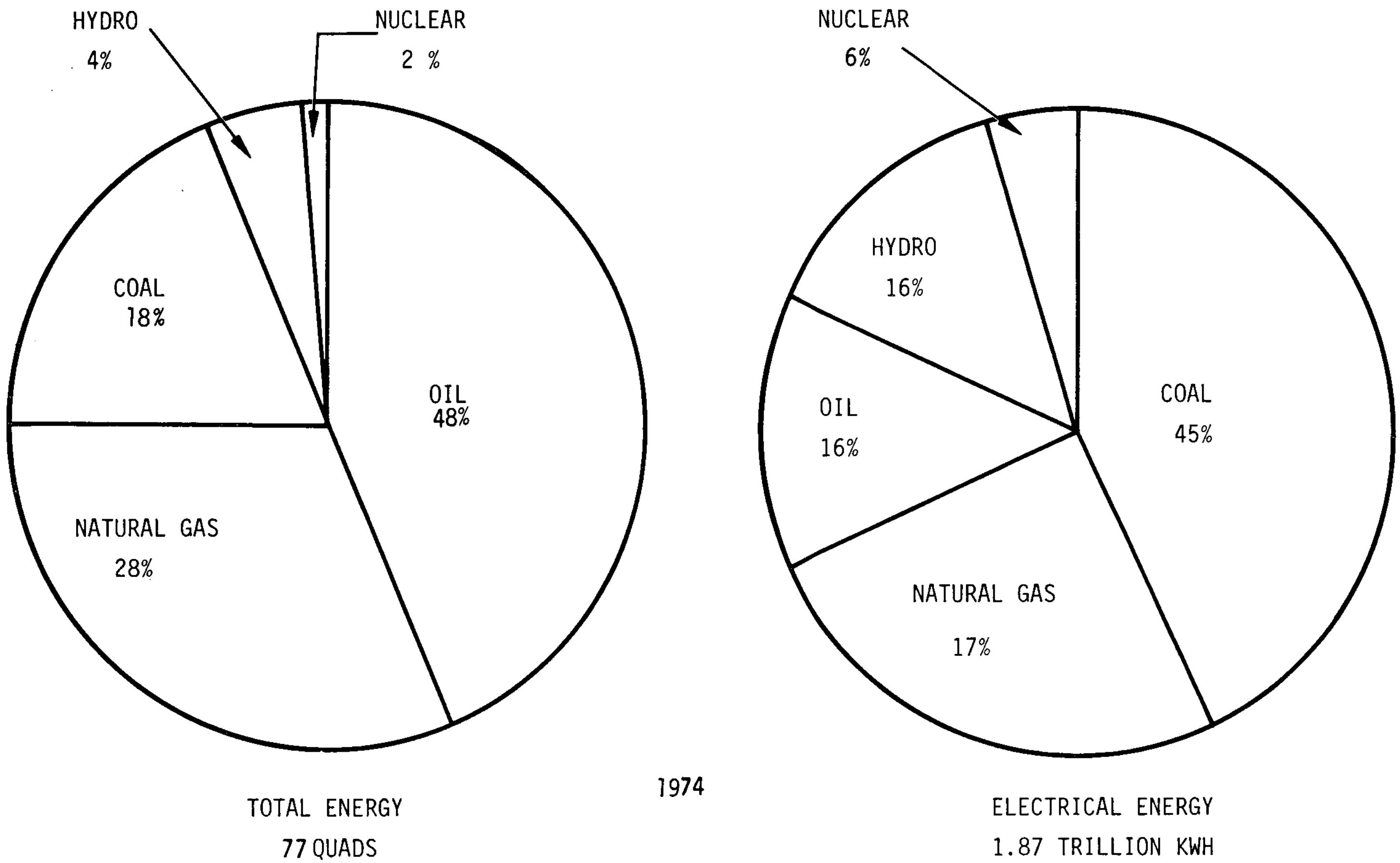
A question of vital importance to the nation is whether the resource base in the U.S. is adequate to maintain this distribution of production in the future. The estimated fuel resource base available in the U.S. for future energy production is shown in Figure III F-13. The resource base, in this case, was defined as the quantity of energy available at three to four times current prices. Since this analysis is oriented toward long-range energy system forecasting, suppose the size of any resource is measured by the following criterion: a resource will be considered large if it is capable of meeting the U.S. energy requirement to the year 2000 by itself; otherwise, it will be considered small. Assuming a continuation of the 2.7%/year growth rate for total energy, the U.S. will consume 2700 quads between 1975 and the year 2000. If the growth rate were reduced to zero in the next few years, the U.S. would still consume about 1900 quads over the same time span. With either assumption, Figure III F-13 shows that the supply of oil and natural gas is small. The amount of coal is large, provided the coal-bearing regions in the western states are strip-mined. Although the amount of energy available from the Light Water Reactor (LWR) is small, the amount of energy available from the LMFBR is very large. Furthermore, the energy available from the LMFBR exceeds the amount required to take the U.S. to the year 2000 by a factor of about 50.

It is important for energy resource planning that the resource base available for the production of electricity, i.e., coal and uranium, is large, while the resource base available for the production of liquid fuel, i.e., oil, is small. As a consequence, oil should be conserved in the future for those applications for which it is uniquely suited, while electrical energy produced by coal and uranium should be substituted for energy produced by oil wherever possible. Thus, the growth rate for electrical energy may not diminish in the future; in fact, it may increase.



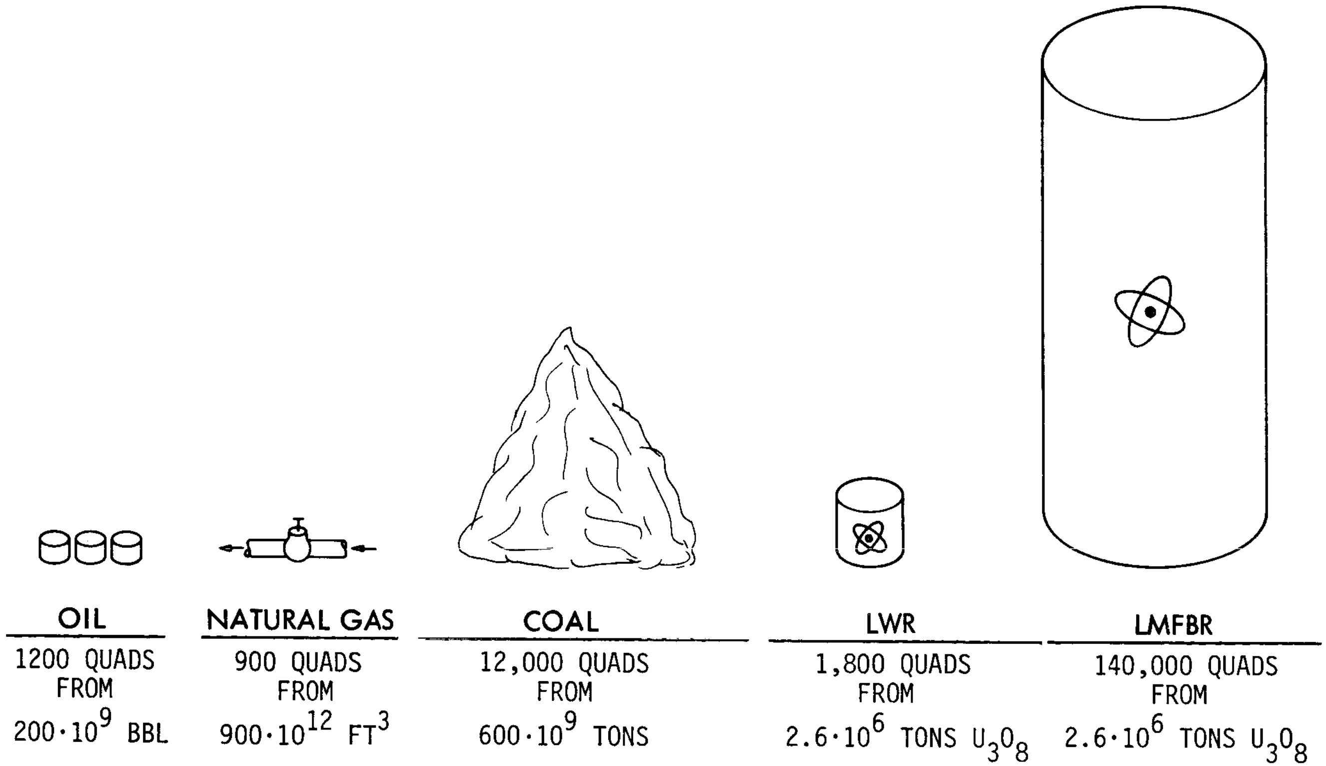
HISTORICAL ENERGY PRODUCTION RATES IN THE U.S.

Figure III F-11



APPROXIMATE U.S. ENERGY PRODUCTION RATES BY PRIMARY SOURCE

Figure III F-12

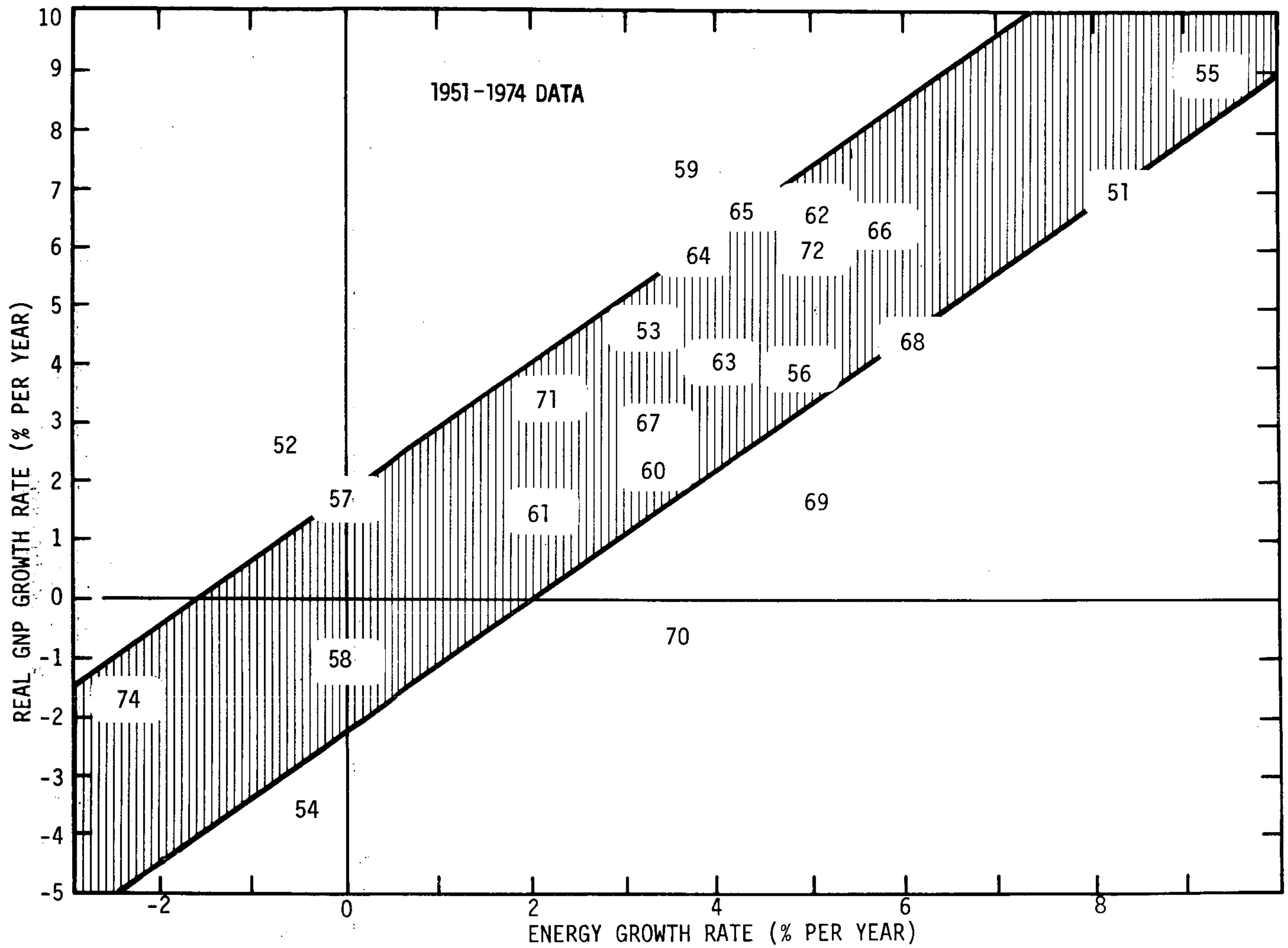


U.S. energy requirement to the year 2000 ≈ 2,700 quads at a 2.7%/yr growth rate
*At 3 to 4 times current prices

RESOURCE BASE* AVAILABLE TO U.S.

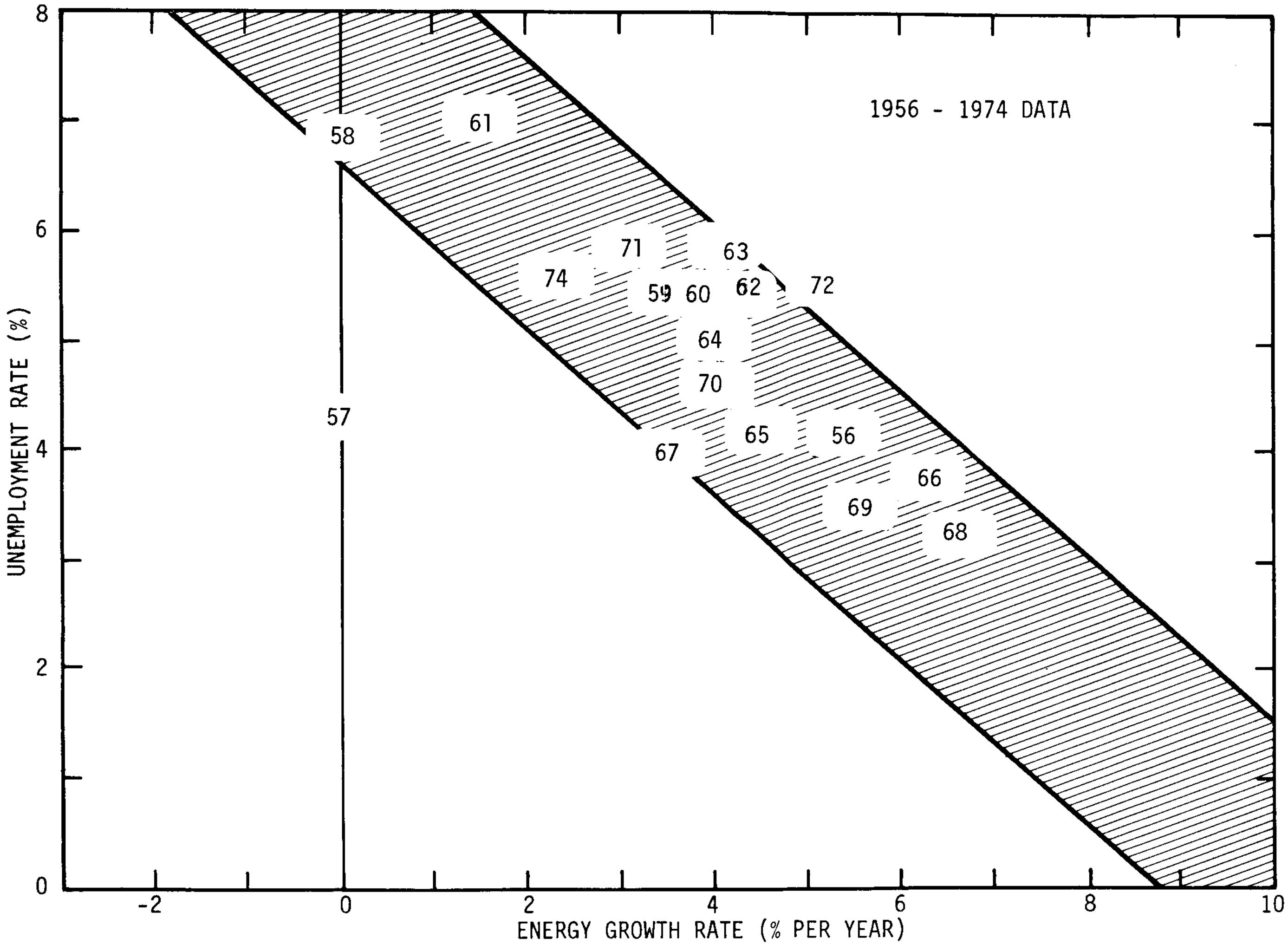
Figure III F-13

The importance of maintaining an adequate supply of energy at a reasonable price should not be underestimated. Energy is as important to an industrial society as any of the classical economic inputs such as land, labor, and capital. In fact, energy production, economic growth, and employment are closely coupled, as Figures III F-14 and III F-15 show. Figure III F-14 shows the relationship which has existed historically between the growth rate of energy and the real growth rate of the Gross National Product (GNP).[14-16] The growth rate, i.e., the fractional change from year to year, has been plotted rather than the absolute magnitude of either energy consumption or GNP. This is because we are interested in the effect of a change in one variable upon a change in the other, rather than in a series of quasi-equilibrium states. Note that high energy growth rates are correlated with high GNP growth rates, and conversely. Since the rate of unemployment can be related to changes in the GNP, one might expect to find a correlation between the energy growth rate and the unemployment rate. Such a correlation does in fact exist, and it is shown in Figure III F-15.[16,17] Note that high energy growth rates are correlated with low unemployment rates in this country, and conversely. While the precise cause and effect between energy, GNP, and unemployment changes may not be known, it is also clear that a severe and rapid reduction in the energy growth could imply a severe economic dislocation.



RELATIONSHIP BETWEEN ANNUAL CHANGES IN ENERGY USE AND GNP

<u>**Figure III F-14**</u>



RELATIONSHIP BETWEEN ANNUAL CHANGES IN ENERGY USE AND UNEMPLOYMENT

Figure III F-15

4. THE STATUS OF THE LMFBR

Contrary to the thrust of the arguments of some commentors, the Liquid Metal Fast Breeder Reactor is not an embryonic technology with a high degree of uncertainty. The basic principles were developed in the earliest days of nuclear power. The technical feasibility was first proven in the U.S. nearly 25 years ago with the operation of EBR-I, while EBR-II has been operating successfully for 12 years. Furthermore, large LMFBR power plants are under construction or in varying stages of design in Great Britain, France, Germany, U.S.S.R., Japan, and the U.S.--i.e., in the major industrial nations of the world. The status of the principal LMFBR projects in these countries is shown in Table III F-6. It is evident from this table that technical feasibility is not the problem; the goal of the major industrial nations is obviously to construct and operate large power plants. For this reason, the LMFBR should not be confused with power sources such as solar and fusion, which are in an earlier stage of development.

Table III F-6

STATUS OF MAJOR LMFBR PROJECTS

Country	Name	Approximate Power (MW_t)	(MW_e)	Status
U.S.S.R.	BN-350	1000	150+Process	Criticality achieved in 1972
	BN-600	1470	600	Construction is almost finished
	BN-1500	3750	1500	Currently being designed
France	PHENIX	563	250	Reached full power 3/13/74
	SUPER PHENIX	3000	1200	Construction scheduled to begin in 1975
Great Britain	PFR	559	248	Criticality achieved in 1974
	CFF	2900	1160	Construction may begin about 1978
Germany	SNR-300	736	282	Commercial operation scheduled for 1979
	SNR-2	3000	1200	Early stages of design
Japan	MONJU	714	300	Target criticality date is 1980
U.S.	FTR	400	---	Scheduled for completion in 1978
	CRBR	975	350	Scheduled for completion in 1983

5. MODEL CHARACTERISTICS, INPUT DATA, AND ASSUMPTIONS

The model used to analyze the nuclear energy economy is based on the mathematical technique of linear programming. This is an established technique, and is often used to analyze economic[19,20] and energy system forecasting problems.[2,12,21-24] The model functions as follows. Within the model, power plants compete with each other for a share of the market based on their capital cost, fuel cost, and fuel supply. The model utilitizes this competition to select a growth pattern which minimizes the total energy cost over the planning horizon. This technique has the advantage of always producing growth patterns consistent with the cost assumptions. The basic tenet of this model is that the utilities are sufficiently informed so as to always distinguish the power plant with the lowest total power cost, and that the vendors are sufficiently competitive so that the plant with the lowest cost will always sell for the lowest price. Thus, the minimum cost nuclear industry growth pattern is developed, and any deviation from this pattern will result in higher nuclear energy costs.

All analysis in this report was performed in constant dollars. Thus, the calculated changes in energy costs are real--i.e., in addition to general movements in wages and prices.

A. The Discount Rate

Dollar benefits obtainable from the LMFBR are quoted at two discount rates: 7.5% and 10%. The discount rate which should be employed in a long-range energy forecasting study has been in dispute. Manne[2] and Stauffer[3] have advocated lower discount rates, while Cochran[5] and Rice[11] have advocated higher discount rates. Since the results of any long range forecasting study are quite sensitive to the discount rate, a discussion of the subject is appropriate.

Some economists[3] are of the opinion that the discount rate employed in energy forecasting studies theoretically should be that rate which measures the time preference of society. That is, it should reflect the degree to which society favors a return today over a return in the future. The use of such a rate would characterize the optimal growth path for the economy, i.e., society would be exactly compensated for the act of saving. Given perfect capital markets, it has been shown that the return on private capital will equal the return on long-term government bonds, and both will equal the rate of social time preference--i.e., the willingness of society to save.[22] However, such things as large government investments in money markets, the inability of economic units to borrow and loan at identical rates, and the corporate income tax, all render capital markets imperfect. Because of this, government bond rates will tend to be lower than the opportunity cost of money, and likewise the return on private capital will tend to be higher.

In spite of the difficulty, there has been some attempt to determine a discount rate for public investments. Stockfish, in an attempt to measure the opportunity cost of government investment, found the before-tax average return on private capital to be 12.0%.[23] After discounting for inflation, he obtained 10.4%.

The return on long-term government bonds forms the minimum lower bound for the correct discount rate. This is currently about 6.5%, and when discounted for inflation, a value of 4.0% is obtained. It has been suggested that public investments be evaluated with a discount rate equal to the average of the government and private returns.[24] Thus, following this suggestion, a discount rate of about 7% would be appropriate.

The optimum rate of growth requires that investment be undertaken at a rate such that the increased output, resulting from an additional dollar of investment in productive capacity, precisely equals the willingness of society to invest in such capacity. This is known as the marginal product of capital and is in essence the ideal discount rate. The studies discussed above are attempts to obtain a discount rate from the average product of capital. In general, because of diminishing returns to capital, the marginal product of capital is less than the average product. Hence, a discount rate calculated from the average product of capital will tend to be too high. Considering both the imperfection of capital markets and the difference between the average and marginal product of capital, it should be apparent that the correct discount rate is not truly measurable; it can only be estimated and a range established. The arguments outlined previously suggest a value of 7% with a range of 4.0% to 10.4%. The use of discount rates on the high side of this range will result in a level of saving less than that which society has revealed it prefers, while the use of rates on the low side would result in an excess of saving. Thus, the use of rates in the center of the range seems most appropriate. In this study, discount rates of 10% and 7.5% were used.

B. Basic Input Data and Assumptions

A forecasting study which evaluates a long-range energy development strategy requires estimates of future costs, demands, and availabilities. In this study, estimates were required for future electrical energy requirements, future uranium enrichment costs, U_3O_8 cost versus supply estimates, and future nuclear plant capital costs.

1. Estimated Electrical Energy Requirements

The current annual electrical energy demand in the U.S. is about 2.0 trillion kilowatt-hours, and the historical rate of increase has been about 7%/yr for a period of 55 years. In this study, however, this trend was not assumed to continue--all estimates of future electrical energy requirements were based on a declining growth rate. Thus, the forecasts used in this study are in no way contingent upon a continuation of the long-term historical growth pattern.

The projected electrical energy growth patterns used in this analysis are shown in Tables III F-7 and III F-8. As the tables show, three basic growth patterns were assumed. The small energy growth pattern assumes an electric energy requirement of 7.0 trillion kilowatt-hours in the year 2000. This is based upon an assumed electrical energy growth rate of 5.3%/yr in the first decade (1975 to 1985) and 2.6%/yr in the last decade (2015 to 2025), with an average growth rate of 4.1%/yr over the five decade interval. In the year 2000, nuclear plants supply about 53% of the electrical energy requirement, and the installed nuclear capacity is 625 Gwe. The reference energy growth pattern assumes an electrical energy requirement of about 8.1 trillion kilowatt-hours in the year 2000. This is based upon an assumed electrical energy growth rate of 5.9%/yr in the first decade and 4.6%/yr in the last decade, with an average growth rate of 5.2%/yr over the five decade interval. In the year 2000, nuclear plants supply 67% of the electrical energy requirement, and the installed nuclear capacity is 900 Gwe. The large electrical energy growth pattern assumes an electrical energy requirement of 9.6 trillion kilowatt-hours in the year 2000. This is based on an assumed electrical energy growth rate of 6.7%/yr in the first decade and 5.2%/yr in the last decade, with an average growth rate of 5.9%/yr over the five decade interval. In the year 2000, nuclear plants supply 79% of the electrical energy requirement, and the installed nuclear capacity is 1250 Gwe.

Table III F-7

PROJECTED ELECTRICAL ENERGY REQUIREMENTS

(energy in 10^{12} kwh, capacity in Gwe)

Energy Requirement	Production Category	1975	1985	2000	2025
	Total Electric Energy	2.0	3.4	7.0	15.6
Small	Nuclear Electric Energy	0.2	1.0	3.7	9.8
	Installed Nuclear Capacity	37	160	625	1730
	Total Electric Energy	2.0	3.6	8.1	27.5
Reference	Nuclear Electric Energy	0.2	1.2	5.4	21.3
	Installed Nuclear Capacity	39	195	900	3700
	Total Electric Energy	2.0	3.9	9.6	37.6
Large	Nuclear Electric Energy	0.2	1.5	7.6	29.5
	Installed Nuclear Capacity	43	245	1250	5140

Table III F-8

PROJECTED ELECTRICAL ENERGY GROWTH RATES

	Growth Rate (%)		
Energy Requirement	Initial 1975-1985	Final 2015-2025	Average 1975-2025
Small	5.3	2.6	4.1
Reference	5.9	4.6	5.2
Large	6.7	5.2	5.9

A number of studies in recent years have predicted electrical requirements in the year 2000 which range from a low value of about 2 trillion kilowatt-hours to a high value of about 10 trillion kilowatt-hours.[25-32] Note that the electrical energy requirement in the year 2000 in this study ranged from 7.0 to 9.6 trillion kilowatt-hours, and so our values fall within the established range. However, without exception, the other studies either assumed an increasing electrical energy price, or simply did not include price in their model. The model and some of the assumptions used in each of these studies are indicated in Table III F-9.

It is important to note that the LMFBR is a technological development which is capable of changing electrical energy production price patterns. This is simply because the LMFBR produces more fuel than it consumes, and so is capable of eliminating the dependence of the electrical energy economy upon depletable fuel supplies. The introduction of the LMFBR ultimately results in an abundant fuel supply and as was shown in Figure III F-8, falling nuclear electric power costs. Thus, the substitution of electric energy for other forms of energy becomes an important consideration in analyzing future electric energy requirements.

Using the nuclear power cost pattern obtained from our forecasting study, we have calculated future electric energy requirements. This was accomplished with an econometric model which estimated future electrical energy requirements by accounting for the real price of electricity, the real price of a substitute fuel, the change in the population, and the change in the GNP.[32] The elasticity of electrical energy demand with respect to each of these variables was computed using data from 1948 to

Table III F-9

FORECASTS OF ELECTRICAL DEMAND

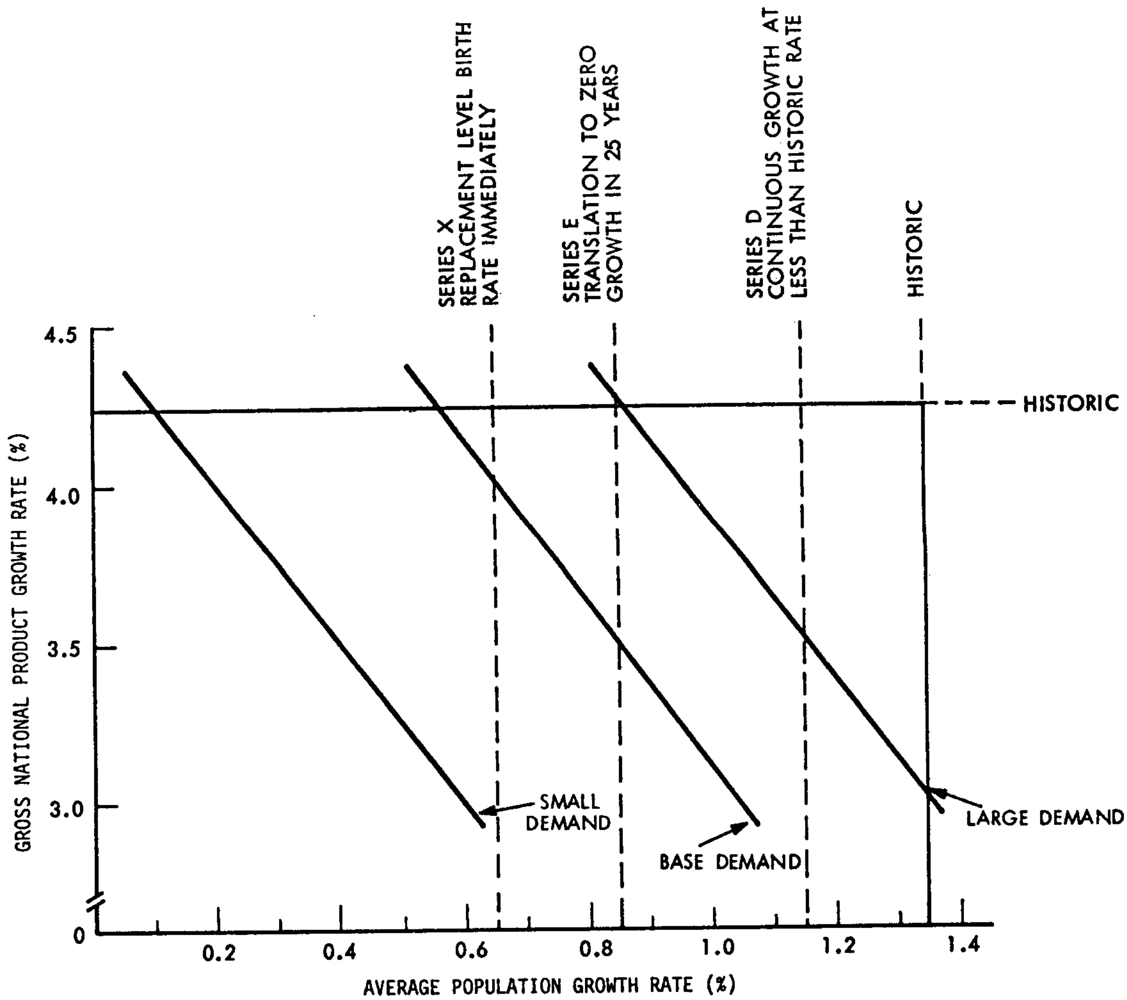
	Source	Type	Annual GNP Change (%)	Annual Electricity Price Change (%)	Elec. Demand in 2000 (trillion kwhrs)
1.	Ford Foundation[22]				
	a. Historical (continuation of historical trends)	Input-output	+3.45	+ .81	7.96
	b. Technical Fix (historical, with improved efficiency)	Input-output	+3.30	+4.50	7.60
	c. Zero Energy Growth	Input-output	+3.30	+5.60	3.40
2.	Federal Energy Administration[12,18] (extrapolation of recent trends)	Econometric	N/A	N/A	5.54
3.	Dupree-West[26]	Econometric	+4.1	N/A	9.01
4.	Chapman, Tyrrell & Mount[27-29]				
	a. Slowly Rising Energy Prices	Econometric	+4.0	+ .63	3.45
	b. Rapidly Rising Energy Prices	Econometric	+4.0	+3.33	2.01
5.	Hudson-Jorgenson[30]	Input-output	+3.85	+3.5	6.98
6.	Cornell[31]	Econometric	3.1	N/A	10.25
7.	HEDL[32]	Econometric	3.9 to 1990 3.4 to thereafter	+1.0 to 1990 -1.0 thereafter	9.5

1974. An analysis of future energy demand was then made based on the following assumptions. First, the GNP will increase at a rate of 3.9%/yr to 1990 and 3.4%/yr thereafter, the population will increase at the rate of 1.0%/yr to 1990 and 0.7%/yr thereafter, the real price of a substitute fuel will increase at the rate of 4%/yr to 1985 and 3%/yr thereafter, and finally, the real price of electricity will increase at the rate of 1%/yr to 1990 and will decrease at the rate of 1.0%/yr thereafter. With these assumptions, none of which are unreasonable, the demand for electrical energy was found to be 9.5 trillion kilowatt-hours in the year 2000. Note that the 9.5 trillion kilowatt-hours corresponds quite closely to the large energy projection used in this study--implying that the reference energy projection should be considered to be conservative.

As the above discussion indicates, a projected electrical energy demand is inherently associated with a projected rate of change of population and GNP. Thus, the degree of conservatism in an electrical energy requirement can be assessed by comparing the associated population and GNP projections with the historical values. Such a comparison is shown in Figure III F-16. Four population growth rates are considered in this figure--in the nomenclature of the Census Bureau they are: Series X, E, D, and the historic rate.[33] Series X assumes that the birth rate falls to the replacement level immediately and remains there indefinitely. Series E assumes a transition toward a zero growth state in about 25 years. Series D assumes a continuous growth at a rate less than the historic rate. As the figure shows, if the Series X prediction were correct and the GNP were to increase at a rate of 4.0%/yr, then the electrical energy requirement would be identical to the reference value used in this study. However, an increase in the GNP of 4.0%/yr is less than the historic rate of 4.25%/yr, and so the reference energy demand should be considered to be conservative.

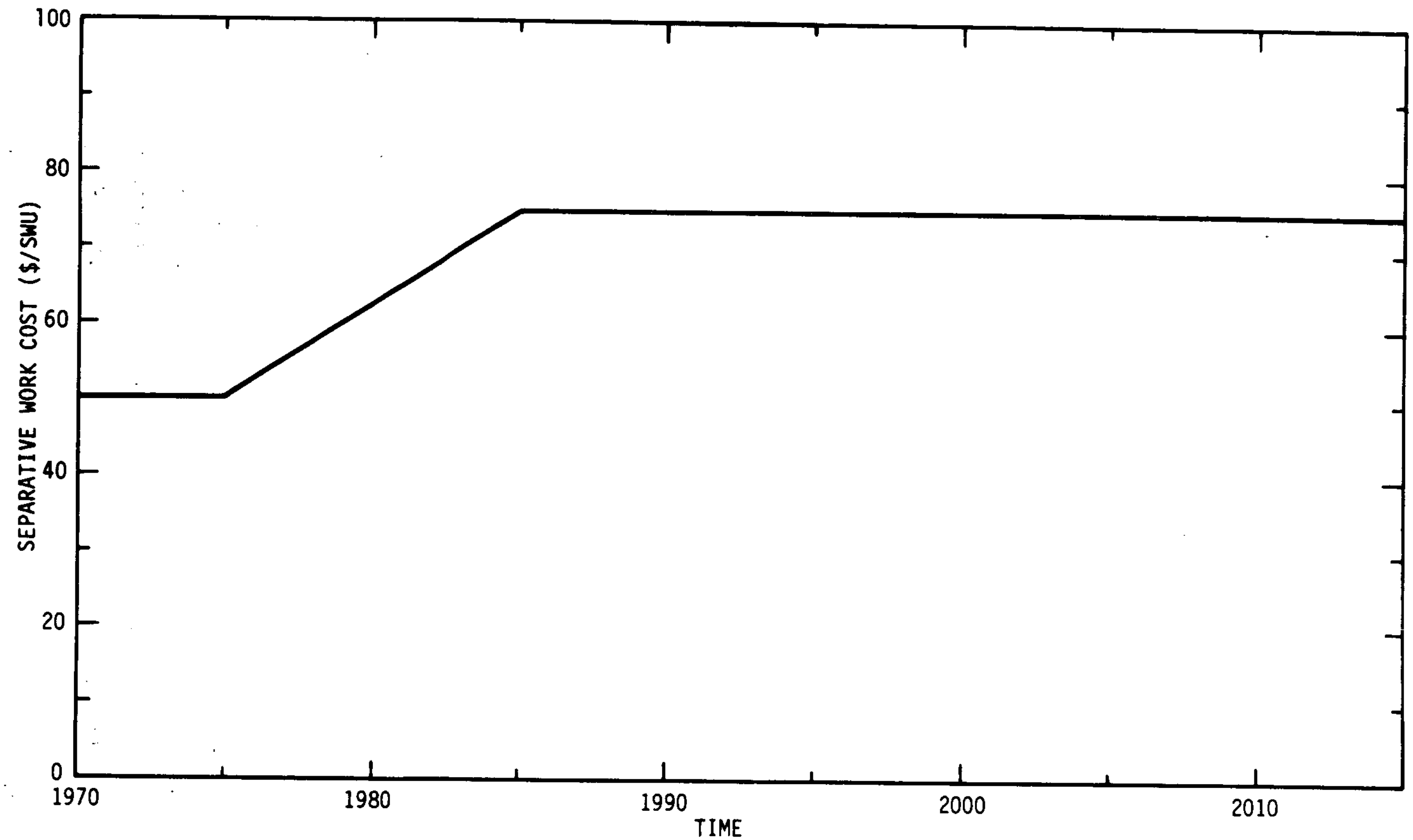
2. Estimated Uranium Enrichment Costs

The uranium enrichment costs used in the study are shown in Figure III F-17. The cost of enrichment was assumed to increase linearly from $50/SWU in 1975 to $75/SWU in 1985, and to remain constant at $75/SWU thereafter.



ESTIMATES OF ELECTRICAL ENERGY REQUIREMENT VERSUS POPULATION AND GNP GROWTH RATE

Figure III F-16



PROJECTED URANIUM ENRICHMENT COSTS

Figure III F-17

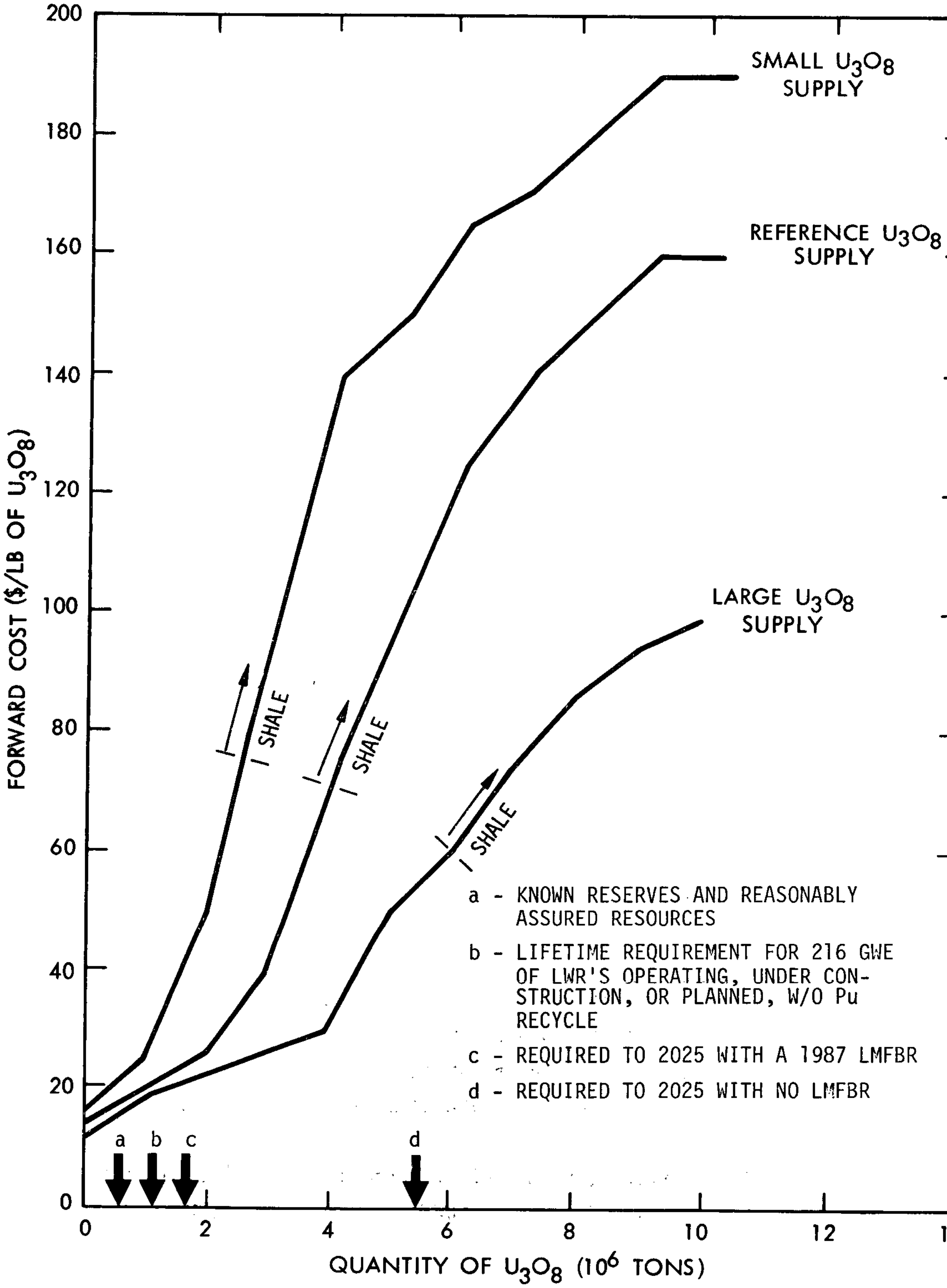
3. U_3O_8 Cost Versus Supply Estimates

The estimates of the cost of U_3O_8 versus the cumulative supply used in this study are shown in Figure III F-18. Three estimates were used: small, reference, and large. The small estimate corresponds to approximately 2 million tons of U_3O_8 available at a cost less than 60 \$/lb, the reference estimate corresponds to approximately 4 million tons available at a cost less than 60 \$/lb, while the large estimate corresponds to approximately 6 million tons available at less than 60 \$/lb. The small estimate corresponds to approximately 2-1/2 million tons of U_3O_8 available before the mining of shale is required, the reference estimate corresponds to approximately 4 million tons of U_3O_8 available prior to the mining of shale, while the large estimate corresponds to approximately 6 million tons of U_3O_8 available before shale must be mined.

It should be noted that the U_3O_8 costs used in this study are substantially less than the prices currently being seen in the marketplace.[34] For example, the Washington Public Power Supply System recently (August 1975) purchased 5.5 million pounds of U_3O_8 at 22 \$/lb,[35] and other recent purchases have been at higher prices. The reference supply curve used in this study would predict a current price of 14 \$/lb. It should be also noted that low U_3O_8 price estimates will favor the converter reactors, and thereby induce conservatism into an LMFBR analysis.

The adequacy of uranium resources is an important concern in assessing an energy development strategy. In view of this, two points should be noted. First, known reserves and reasonable assured resources, as indicated by point (a) in Figure III F-18, consist of about 0.6 million tons of U_3O_8.[36,37] Secondly, the LWR's which are currently operating, under construction, or planned, have a total capacity of 216 Gwe, and these reactors will consume about 1.0 million tons of U_3O_8 during their 30 year operating life without plutonium recycle. Thus, currently planned consumption without plutonium recycle exceeds known reserves and reasonably assured resources by about a factor of 1.5. Moreover, the U_3O_8 finding rate--expressed in pounds per foot of drilling--declined from 5 lb/ft in 1971 to about 1 lb/ft in 1974. Thus, larger exploration efforts in recent years have resulted in smaller additions to reserves.[37]

In this analysis, it was found that the nuclear industry--without the LMFBR but with plutonium recycle--will require 5.5 million tons of U_3O_8



U_3O_8 COST VERSUS SUPPLY ESTIMATES

Figure III F-18

prior to the year 2025. This assessment included the effect of increasing U_3O_8 prices on the relative competitive position of the LWR and HTGR. Thus, without the LMFBR, 90% of the U_3O_8 required to the year 2025 remains to be found. If the LMFBR were introduced in 1987, the nuclear industry would require approximately 1.8 million tons of U_3O_8 prior to 2025, and only negligible quantities after that date. Hence, the LMFBR--when introduced early--substantially reduces the risk associated with an uncertain U_3O_8 supply.

Finally, while the curves of U_3O_8 cost versus quantity may appear to be quite precise, it is important to note that they are simply estimates. Most of the U_3O_8 shown in Figure III F-18 has yet to be discovered.

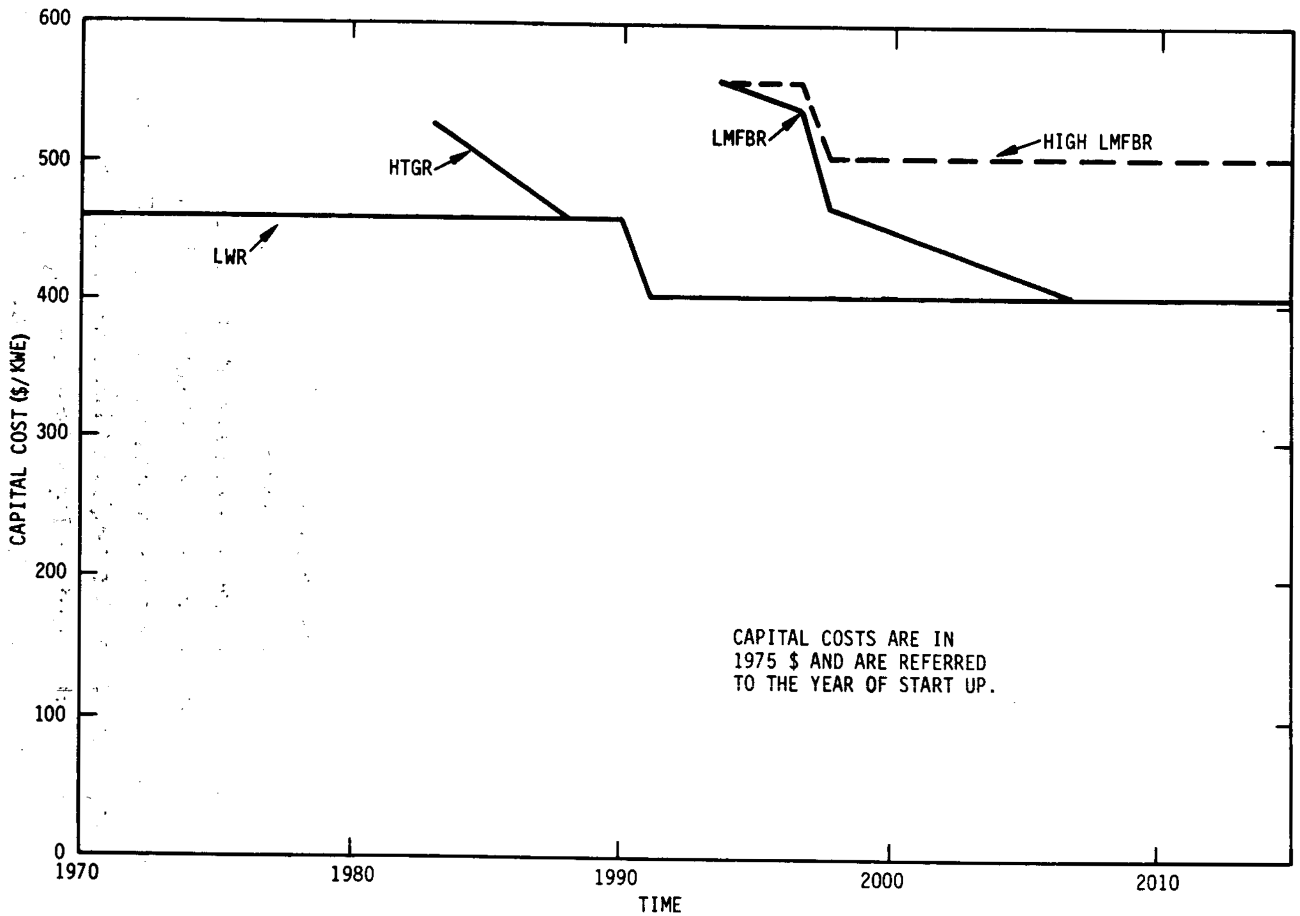
4. <u>Nuclear Plant Capital Costs</u>

The nuclear power plant capital costs used in this study are shown in Figure III F-19. The costs are in 1975 dollars and are referred to the year of start-up.

The capital cost of an LWR was assumed to be 460 $/kwe prior to 1990, and 405 $/kwe after that date. A plant size change from 1300 Mwe to 2000 Mwe was assumed to occur in 1990, and the capital cost change was produced simply by this size change.

The LMFBR was introduced in 1993 at a cost of 560 $/kwe, i.e., 155 $/kwe above the LWR. Thus, at introduction, the LMFBR was assumed to cost 38% more than the LWR. The differential between the two plants was assumed to decrease to zero by the year 2006 via the economies of scale associated with a size change, and also via the classical learning effect. A decrease of 100 $/kwe was associated with the learning process, i.e., the construction of similar plants in a repetitive manner which increases efficiency and reduces unit costs. A variation in which the LMFBR capital cost was assumed to always be at least 100 $/kwe above the LWR was also considered.

The HTGR was introduced in 1983 at a capital cost 65 $/kwe higher than the LWR. This differential was assumed to decrease to zero in 6 years due to the learning effect.



PROJECTED NUCLEAR PLANT CAPITAL COSTS

Figure III F-19

The basis for the capital cost projections, in particular cost differentials between the power plant types, is provided in Section 11.2.3.8.1 of the PFES. However, due to the sensitivity of the benefits to capital cost differentials it was decided it was appropriate to summarize in the following paragraphs the information in this section.

Examination of LWR cost trends indicate that the price of the nuclear steam system has remained relatively constant over the past several years, exclusive of escalation. This has occurred in spite of the cost additions resulting from increased environmental and safety concerns. Thus, it is concluded that the effects of learning and scale of industry operations in the manufacture of nuclear components have led to reductions in some areas of LWR plant costs. These reductions have, unfortunately, been offset by even larger cost increases arising from environmental and safety-related requirements, which increased the scope of work involved in plant construction. In addition, general inflationary cost trends have led to increasing current-dollar costs. The continuation of these LWR trends into the future is uncertain. However, the LWR industry is considered to have reached a relatively mature level. Current LWR cost estimates include all presently implemented environmental and safety requirements and reflect experience gained during the construction of about 37,500 MWe of nuclear capacity as of October 1, 1975. In addition, it is anticipated that future changes required for LWR plants will affect other nuclear plants in a similar manner, and some changes (e.g., thermal discharge limits) would also affect fossil plant costs.

For purposes of the cost-benefit study, it was assumed that any effects from continuing learning or design changes would make little change in the <u>relative</u> cost of LWR plants. It is recognized that the <u>absolute</u> costs of LWR plants may increase or decrease in the future, due to escalation and the changing requirements discussed above. However, this assumption states the belief that those undefined changes will not alter the cost position of the LWR relative to other plant types. Therefore, to provide a reference cost base, the projected LWR capital costs were based on zero learning beyond the plants being ordered for operation in 1981. Capital costs for the other plant types were estimated relative to this reference base.

The estimate of a decrease of about $100/KWe in the differential between LWR and LMFBR capital costs due to learning is considered to represent a conservative viewpoint. This learning takes place over a thirteen year period during which 241 units are placed in operation. The learning curve applicable to the LMFBR in this period results in a learning factor of about 95%. Thus, the learning curve assumed for the LMFBR is extremely conservative in comparsion with typical values of 80 to 90% learning curves applicable to many industries. This conservative approach is acceptable, since the learning curve being used here applies to reductions in the cost differential for the LMFBR, and not to the total cost change.

In considering all factors and utilizing the expertise in the area of cost estimating developed at HNL/ORNL with some assistance from reactor manufacturers and an architect-engineer, it is the position of ERDA for this study that:

(1) The LWR capital costs (in 1975 dollars) will remain fairly constant in the period 1975 to 2020 for units of equal size and siting conditions.

(2) The HTGR capital costs will be rather close to the LWR costs.

(3) The LMFBR costs will show some reduction due to learning starting with its introduction and at a rate which is reasonable in terms of the number of units produced.

6. RESULTS

The role of the LMFBR in the nuclear energy economy has been extensively studied utilizing an analytical forecasting model. The principal variables in the analysis were: the energy demand, the U_3O_8 price, the LMFBR capital cost, and the LMFBR introduction date. The introduction of an advanced power source with a zero fuel cost, such as a solar or fusion source, might be considered a fifth variable. The effect of changes in each of these five variables will be discussed in turn.

A total of 65 cases were analyzed; the results of 63 of these cases in which the energy demand, U_3O_8 supply, LMFBR introduction date, and LMFBR capital cost were varied, both individually and in combination, are summarized in Table III F-10. The other two cases consider the impact of advanced power sources. In each case, the amount of U_3O_8 consumed to 2025, the U_3O_8 price in 2025, the maximum separative work capacity required prior to 2025, and the dollar benefit associated with the LMFBR are shown.

The benefit was calculated at two discount rates: 7.5% and 10%. The 63 cases tabulated in Table III F-10 are not equally probable. The basic data for the reference case, i.e., 4 million tons of U_3O_8 at 60 $/lb, 900 Gwe of installed nuclear capacity in the year 2000, an LMFBR capital cost initially at 155 $/kwe above the LWR and decreasing to parity in 13 years, was developed during the course of an extensive study and should be considered as defining the most probable case. However, since this data is not known with complete certainty, a variation in any one of these variables from the reference value is of definite interest. Multiple variations, i.e., doublet and triplet variations, are also of interest.

The same results are displayed in a more elegant fashion in Figures III F-20 through III F-28. Figure III F-20 shows the benefits as a function of the energy demand and the U_3O_8 supply for a 1987 LMFBR introduction. The benefits range from 150 billion dollars with a large energy demand and small ore supply to 29 billion dollars with a small energy demand and large ore supply. In all cases, the benefits are substantially greater than the development cost. Note that the benefits are not very sensitive to the ore supply when the energy demand is low. This is because the amount of ore consumed with a small energy requirement is small. The benefits are more sensitive to the ore supply when the energy demand is high, but in this case, the sensitivity is inconsequential since the benefits are always large. Figure III F-21 shows the benefit as a function of energy demand and ore supply for a 1993 LMFBR introduction. The benefits range from 98 billion dollars to 19 billion dollars, depending upon the ore supply and energy demand.

Table III F-10

LMFBR FORECASTING RESULTS

Case	LMFBR Introduction Date	U_3O_8 Supply (10^6 tons of U_3O_8 available at 60 $/#)	Energy Demand (Gwe of installed nuclear capacity in year 2000)	LMFBR Capital Cost	U_3O_8 in 2025 Quantity (10^6 tons)	U_3O_8 in 2025 Price ($/#)	Maximum Separative Work (10^6 SWU/yr)	Benefit (10^9 $ @ 7.5%)	Benefit (10^9 $ @ 10%)
1	none	4	900	base	5.5	100	263	-	-
2	1987	"	"	"	1.8	25	45	72	28
3	1993	"	"	"	3.0	40	73	52	19
4	2000	"	"	"	3.7	58	116	32	12
5	none	"	625	"	3.0	40	115	-	-
6	1987	"	"	"	1.2	20	30	31	13
7	1993	"	"	"	2.0	25	48	20	8
8	2000	"	"	"	2.3	27	60	13	5
9	none	"	1250	"	7.5	140	365	-	-
10	1987	"	"	"	2.5	32	63	113	45
11	1993	"	"	"	4.0	75	113	78	28
12	2000	"	"	"	5.1	100	166	48	16
13	none	2	900	"	5.5	150	265	-	-
14	1987	"	"	"	1.8	50	45	94	37
15	1993	"	"	"	2.5	75	73	68	25
16	2000	"	"	"	3.7	120	116	41	15
17	none	"	625	"	3.0	98	115	-	-
18	1987	"	"	"	1.2	25	30	37	15
19	1993	"	"	"	2.0	50	45	25	9
20	2000	"	"	"	2.2	50	62	16	5
21	none	"	1250	"	7.0	170	368	-	-
22	1987	"	"	"	2.5	75	63	149	59
23	1993	"	"	"	4.0	140	113	98	37
24	2000	"	"	"	5.1	150	162	57	19

Table III F-10

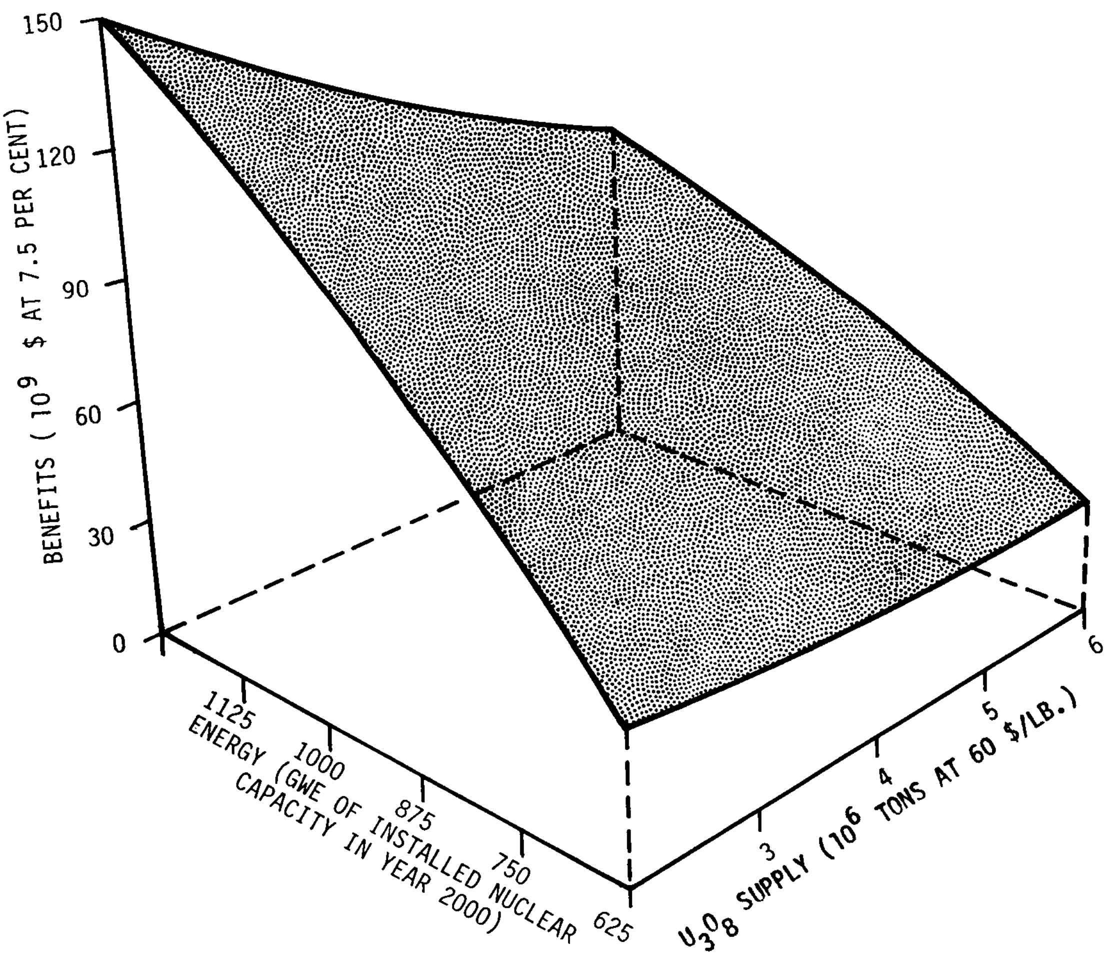
LMFBR FORECASTING RESULTS
(cont'd)

Case	LMFBR Introduction Date	U_3O_8 Supply (10^6 tons of U_3O_8 available at 60 $/#)	Energy Demand (Gwe of installed nuclear capacity in year 2000)	LMFBR Capital Cost	U_3O_8 in 2025 Quantity (10^6 tons)	U_3O_8 in 2025 Price ($/#)	Maximum Separative Work (10^6 SWU/yr)	Benefit (10^9 $ @ 7.5%)	Benefit (10^9 $ @ 10%)
25	none	6	900	base	5.5	50	263	-	-
26	1987	"	"	"	1.8	22	45	59	24
27	1993	"	"	"	3.0	25	73	41	17
28	2000	"	"	"	3.9	30	113	24	9
29	none	"	625	"	3.1	25	115	-	-
30	1987	"	"	"	1.2	18	30	29	11
31	1993	"	"	"	2.0	22	45	19	8
32	2000	"	"	"	2.4	24	59	12	4
33	none	"	1250	"	7.0	74	365	-	-
34	1987	"	"	"	2.5	23	63	86	36
35	1993	"	"	"	4.0	30	10	58	20
36	2000	"	"	"	5.2	50	162	35	12
37	1987	4	900	high	1.8	25	47	32	13
38	1993	"	"	"	2.8	40	75	24	9
39	2000	"	"	"	3.9	73	116	14	5
40	1987	"	625	"	1.3	22	34	11	5
41	1993	"	"	"	2.0	25	50	5	2
42	2000	"	"	"	2.4	32	64	3	1
43	1987	"	1250	"	2.5	32	65	60	24
44	1993	"	"	"	4.0	75	115	43	17
45	2000	"	"	"	5.4	100	166	25	9

Table III F-10

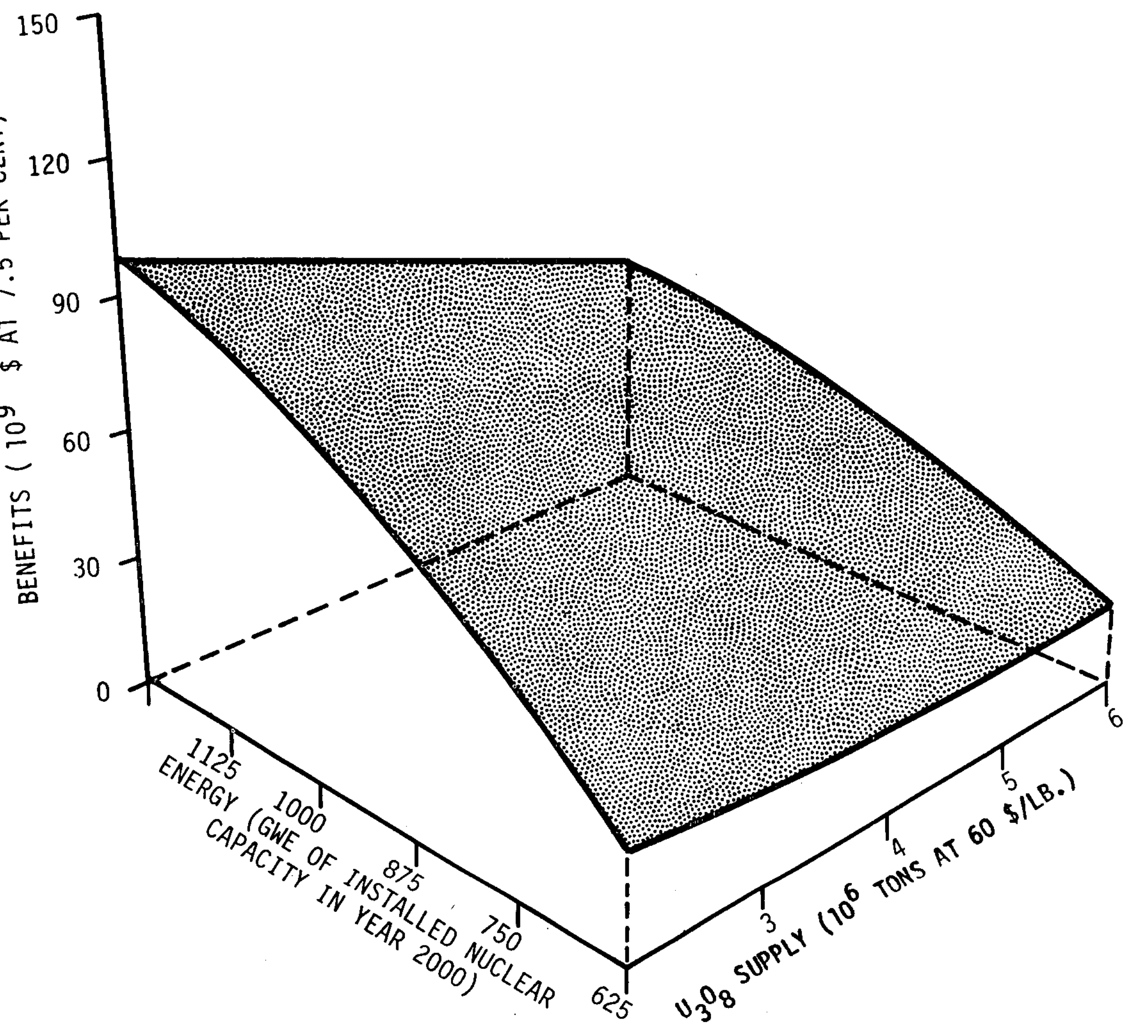
LMFBR FORECASTING RESULTS
(cont'd)

Case	LMFBR Introduction Date	U_3O_8 Supply (10^6 tons of U_3O_8 available at 60 $/#)	Energy Demand (Gwe of installed nuclear capacity in year 2000)	LMFBR Capital Cost	U_3O_8 in 2025 Quantity (10^6 tons)	U_3O_8 in 2025 Price ($/#)	Maximum Separative Work (10^6 SWU/yr)	Benefit (10^9 $ @ 7.5%)	Benefit (10^9 $ @ 10%)
46	1987	2	900	high	1.8	50	45	55	22
47	1993	"	"	"	2.7	75	75	40	15
48	2000	"	"	"	3.8	130	116	23	8
49	1987	"	625	"	1.9	22	50	17	7
50	1993	"	"	"	3.0	25	70	10	4
51	2000	"	"	"	2.2	50	62	6	2
52	1987	"	1250	"	2.5	75	64	96	38
53	1993	"	"	"	4.0	140	112	62	23
54	2000	"	"	"	5.4	150	163	33	12
55	1987	6	900	"	1.9	22	50	20	9
56	1993	"	"	"	3.0	25	70	13	6
57	2000	"	"	"	4.1	30	115	6	3
58	1987	"	625	"	1.4	20	34	10	4
59	1993	"	"	"	2.1	22	48	5	2
60	2000	"	"	"	2.6	23	64	3	1
61	1987	"	1250	"	2.5	23	65	35	14
62	1993	"	"	"	4.4	30	113	22	9
63	2000	"	"	"	5.5	50	163	12	5



LMFBR BENEFITS VERSUS ENERGY DEMAND AND U_3O_8
SUPPLY FOR A 1987 INTRODUCTION

Figure III F-20



LMFBR BENEFITS VERSUS ENERGY DEMAND AND U_3O_8
SUPPLY FOR A 1993 INTRODUCTION

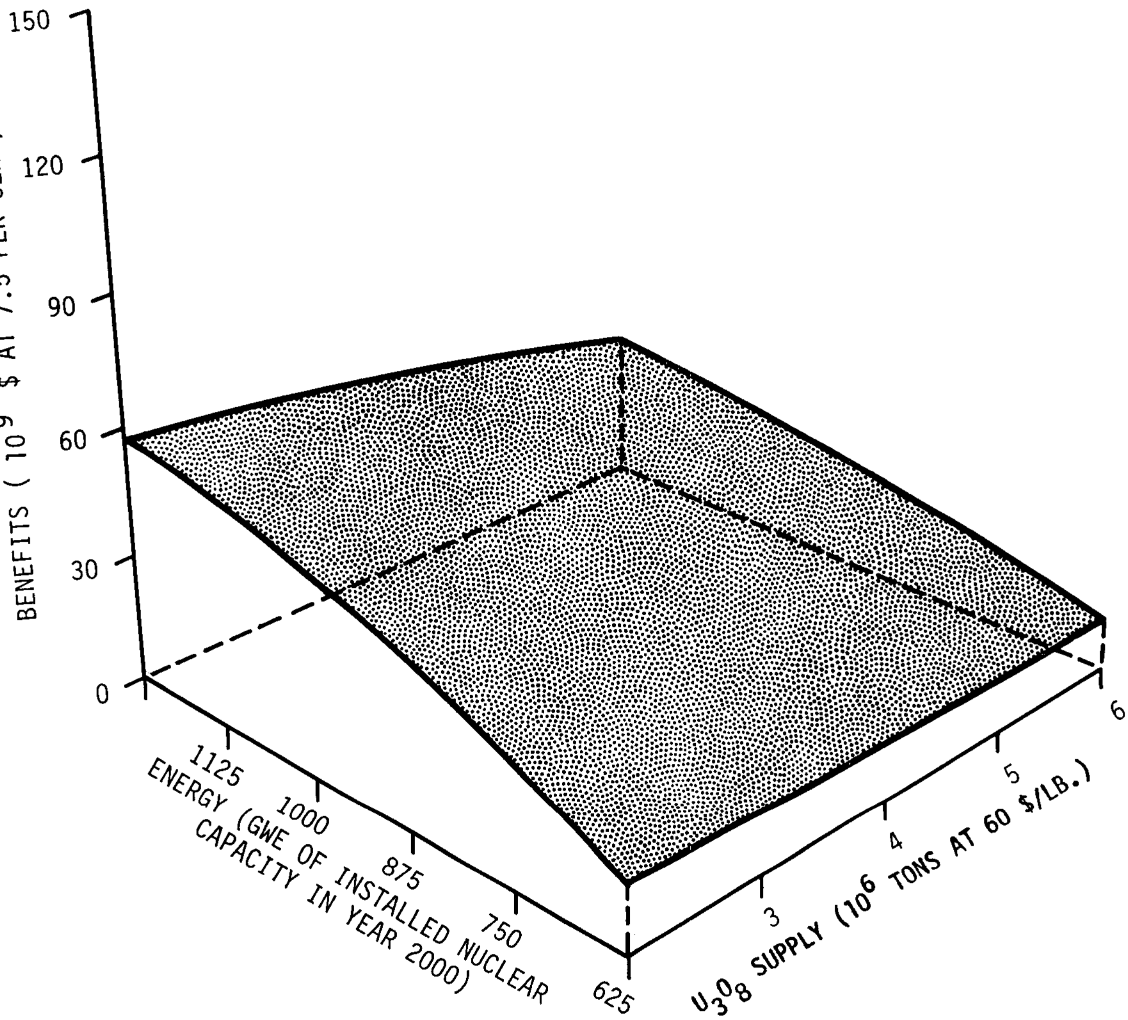
Figure III F-21

Again, the benefits are always significantly greater than the development cost. Similar results are shown in Figure III F-22 for a year 2000 introduction. Note that the benefits are very sensitive to the introduction date, and since the benefits are simply the discounted reduction in total power cost, a delay of the LMFBR will substantially increase electrical power costs. Thus, the argument that delaying the LMFBR will not reduce benefits nor increase power costs[5,11] is simply incorrect. The delay effect is illustrated more explictly in Figures III F-23 and III F-24, where the benefits are plotted first as a function of the introduction date and the ore supply, and secondly as a function of the introduction date and the energy demand. In each case, delaying the LMFBR from 1987 to 2000 reduces the benefits by a factor of two to three.

The effect of a high LMFBR capital cost upon the benefit for a breeder introduced in year 2000 is shown in Figure III F-25. Even with a high capital cost, the LMFBR benefit exceeds the development cost except for situations where the energy demand is low and the uranium supply is base and large. In the case of a large energy demand or a small ore supply, the benefit exceeds the development cost by a substantial margin.

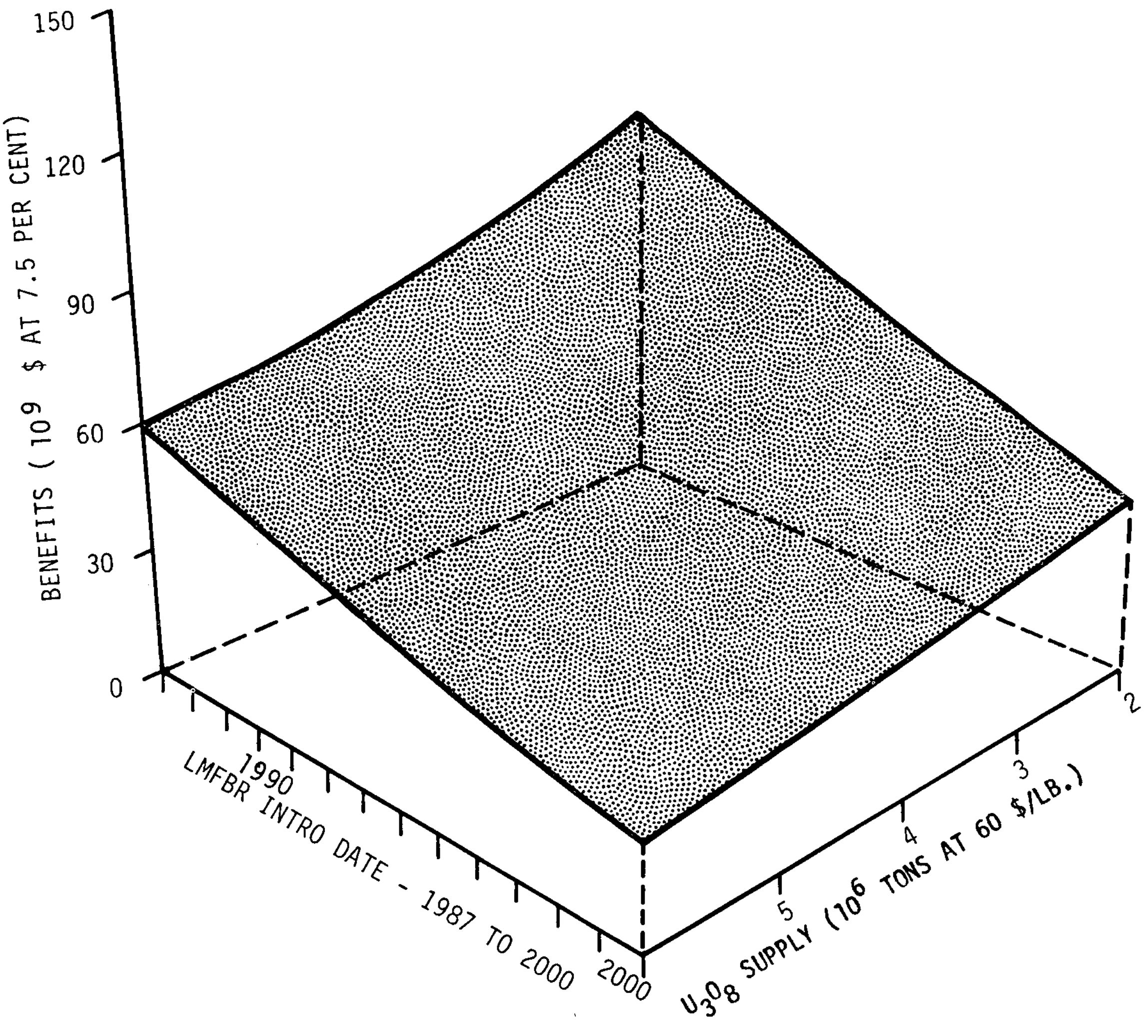
The average nuclear power cost in the U.S. as a function of time and the associated nuclear industry growth pattern is shown for selected cases in Figures III F-26 through III F-31. Recall that Figure III F-8 showed the total power cost with a reference ore supply, energy demand, and capital cost. Also recall that Figure III F-10 showed the growth pattern associated with this case. Note that the LMFBR has the ability to reduce the total nuclear power cost by about 5 mills/kwhr(e) in the year 2020, and nuclear power costs without the LMFBR are 50% higher than with the LMFBR. A reduction of 5 mills/kwhr(e) in the total nuclear power cost in the year 2020 corresponds to a reduction in the cost of electricity of 85 billion dollars per year. This cost reduction occurs because the nuclear economy with the LMFBR has the benefit of an increasing fuel supply, while the nuclear economy without the LMFBR must depend upon a diminishing fuel supply.

Consider next a case which is pessimistic insofar as the LMFBR is concerned, i.e., the case of a large uranium supply and small energy demand. The time dependence of the total power cost for this case is shown in Figure III F-26 and the associated growth pattern is shown in Figure III F-27. In this event, the LMFBR still has the ability to reduce the total nuclear power cost by about 3 mills/kwhr(e) in the year 2020. This reduction corresponds to a savings of about 25 billion dollars/year



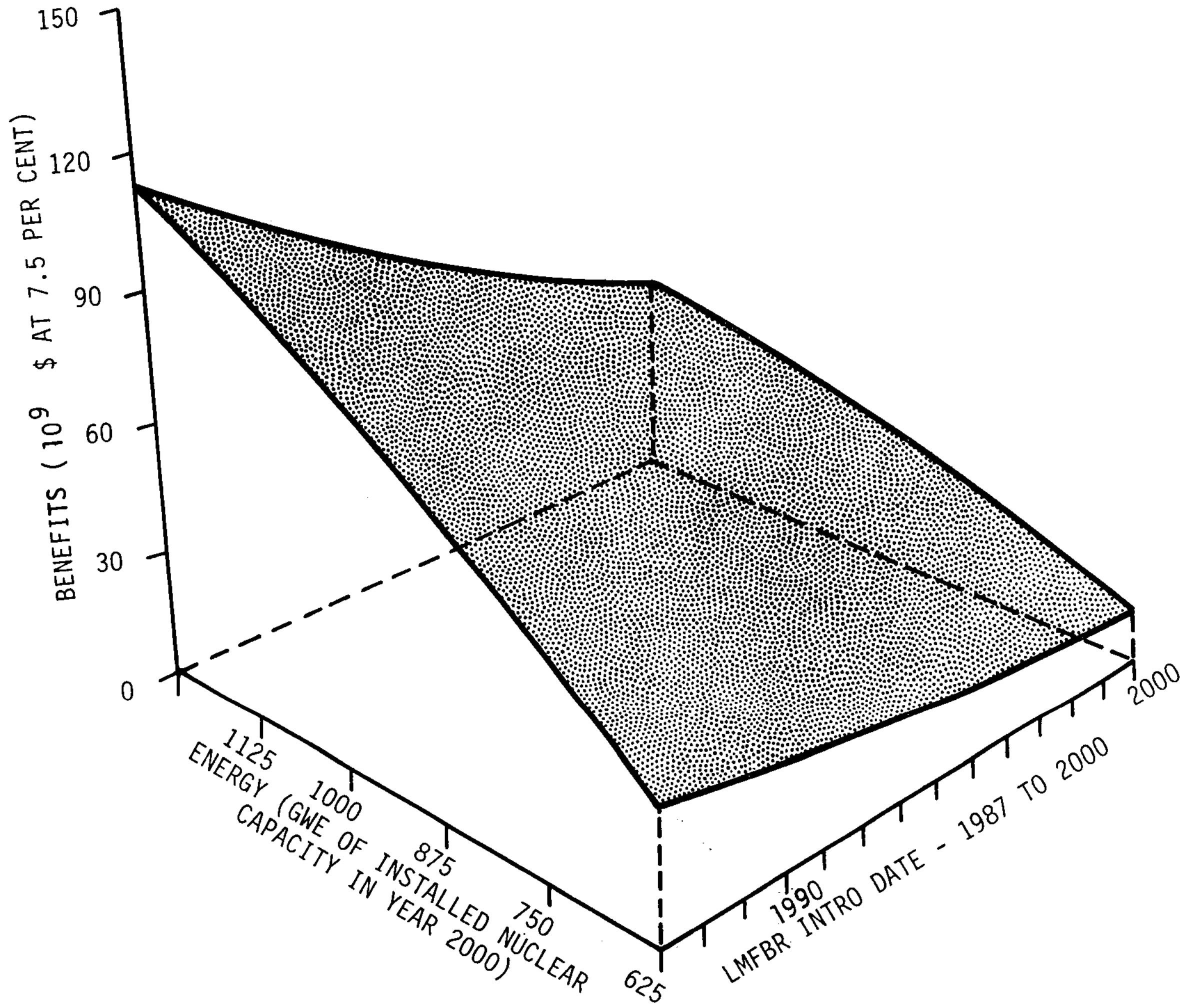
LMFBR BENEFITS VERSUS ENERGY DEMAND AND U_3O_8 SUPPLY FOR A 2000 INTRODUCTION

Figure III F-22



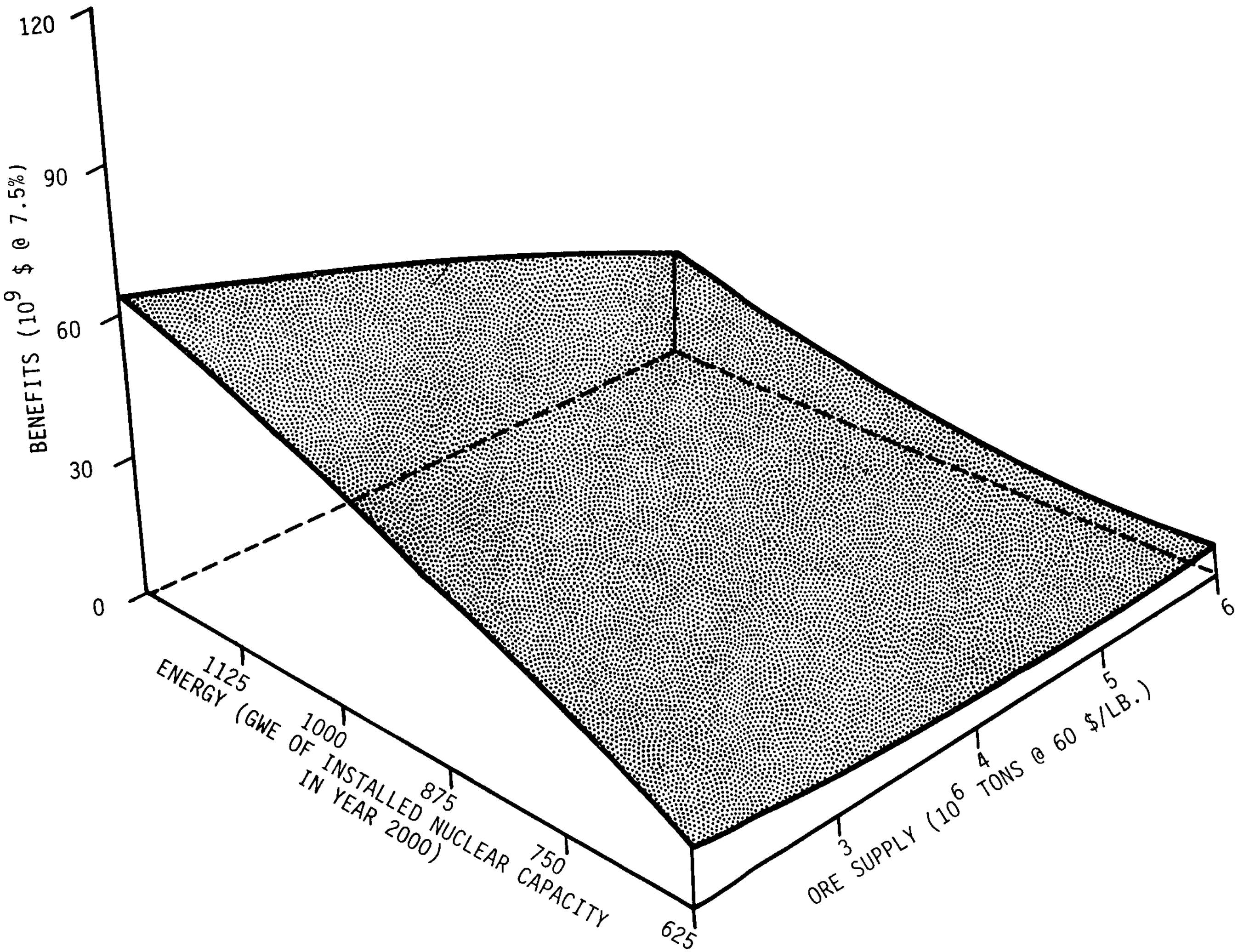
LMFBR BENEFITS VERSUS INTRODUCTION DATE AND U_3O_8 SUPPLY
FOR THE REFERENCE ENERGY REQUIREMENT

Figure III F-23



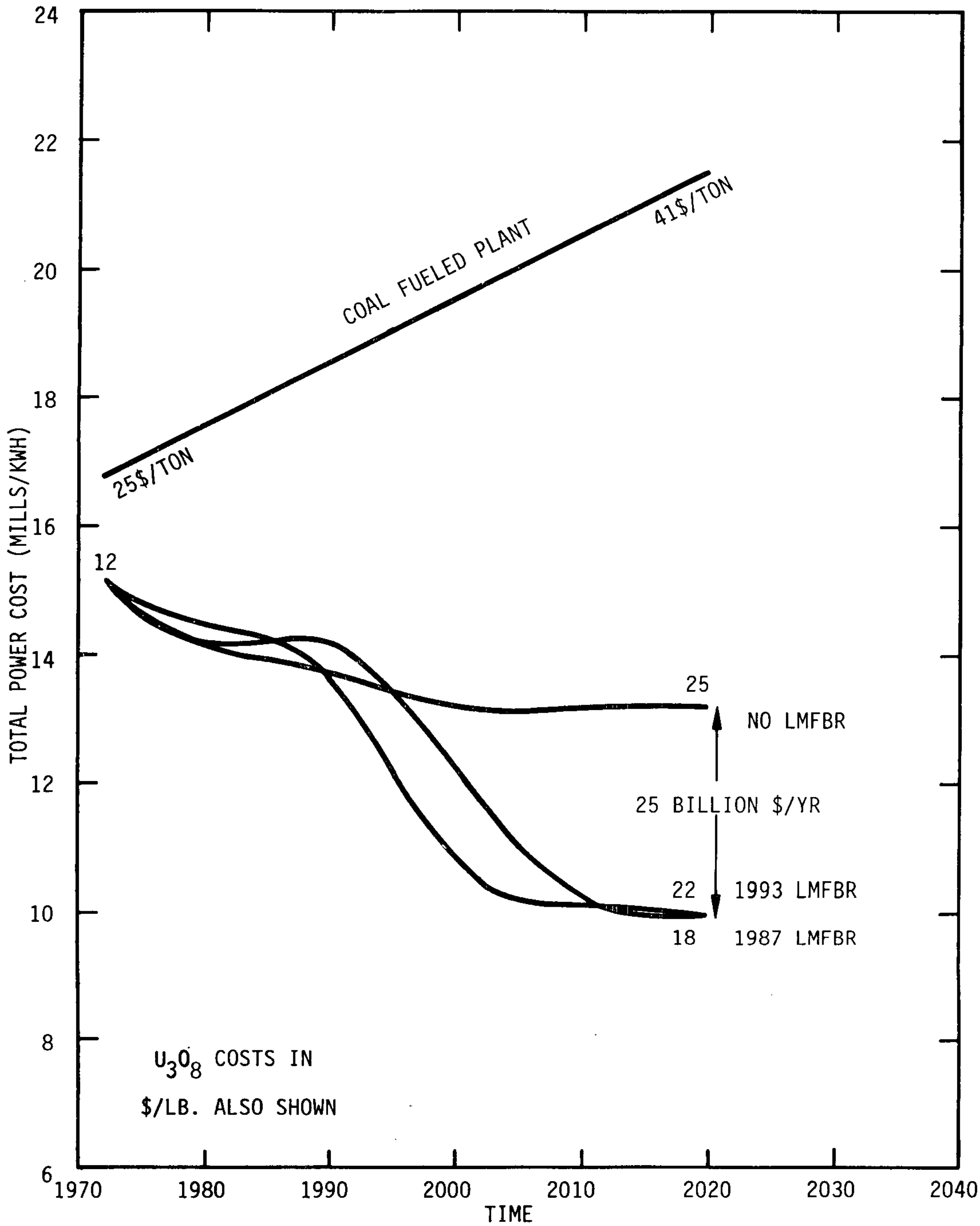
LMFBR BENEFITS VERSUS ENERGY DEMAND AND INTRODUCTION DATE FOR THE REFERENCE ORE SUPPLY

Figure III F-24



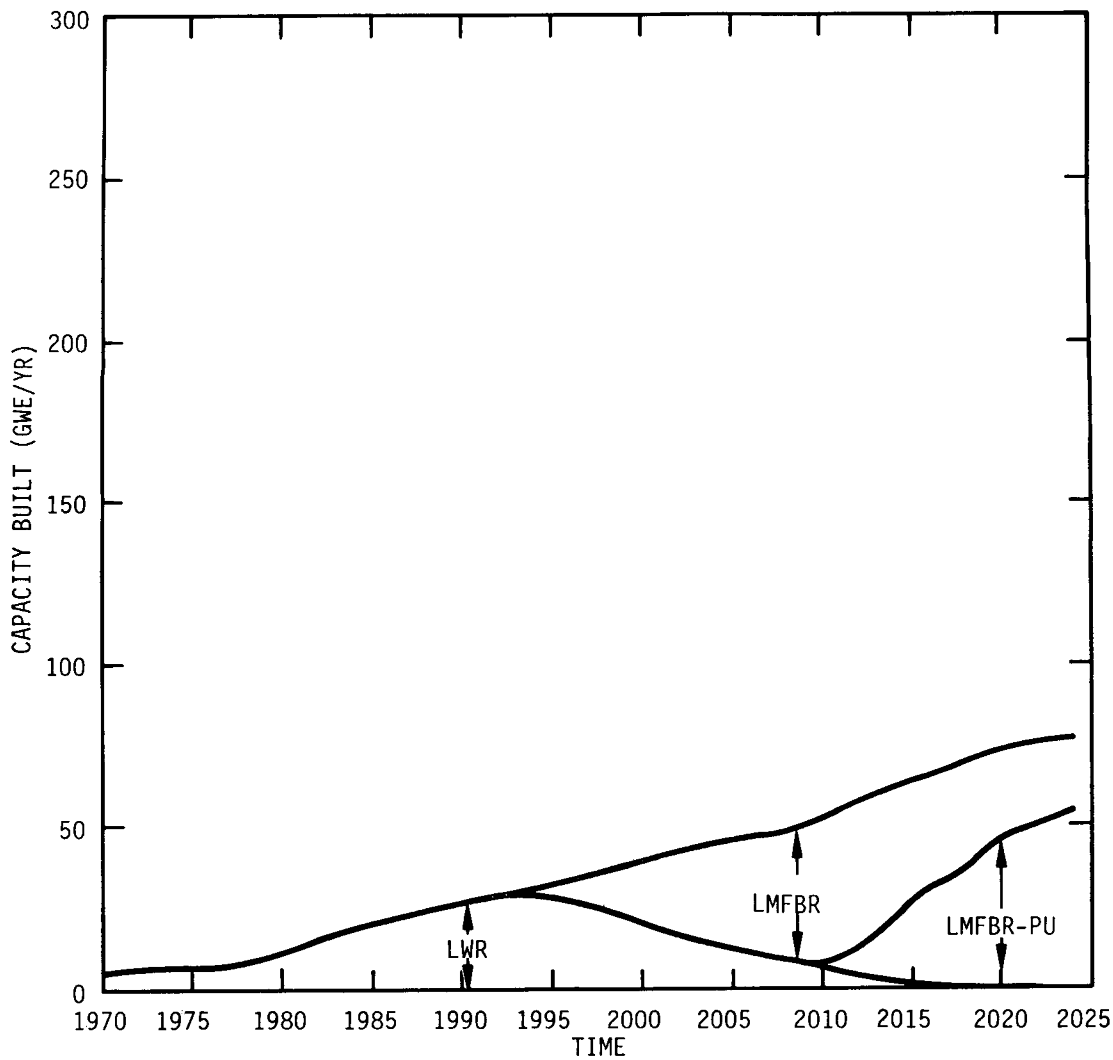
LMFBR BENEFITS IN THE CASE OF A HIGH LMFBR CAPITAL COST

Figure III F-25



AVERAGE U.S. NUCLEAR POWER COSTS (1975-2025)
LARGE URANIUM SUPPLY AND SMALL ENERGY DEMAND

Figure III F-26



U.S. NUCLEAR POWER GROWTH PATTERN
LARGE ORE SUPPLY AND SMALL ENERGY DEMAND - 1993 LMFBR

Figure III F-27

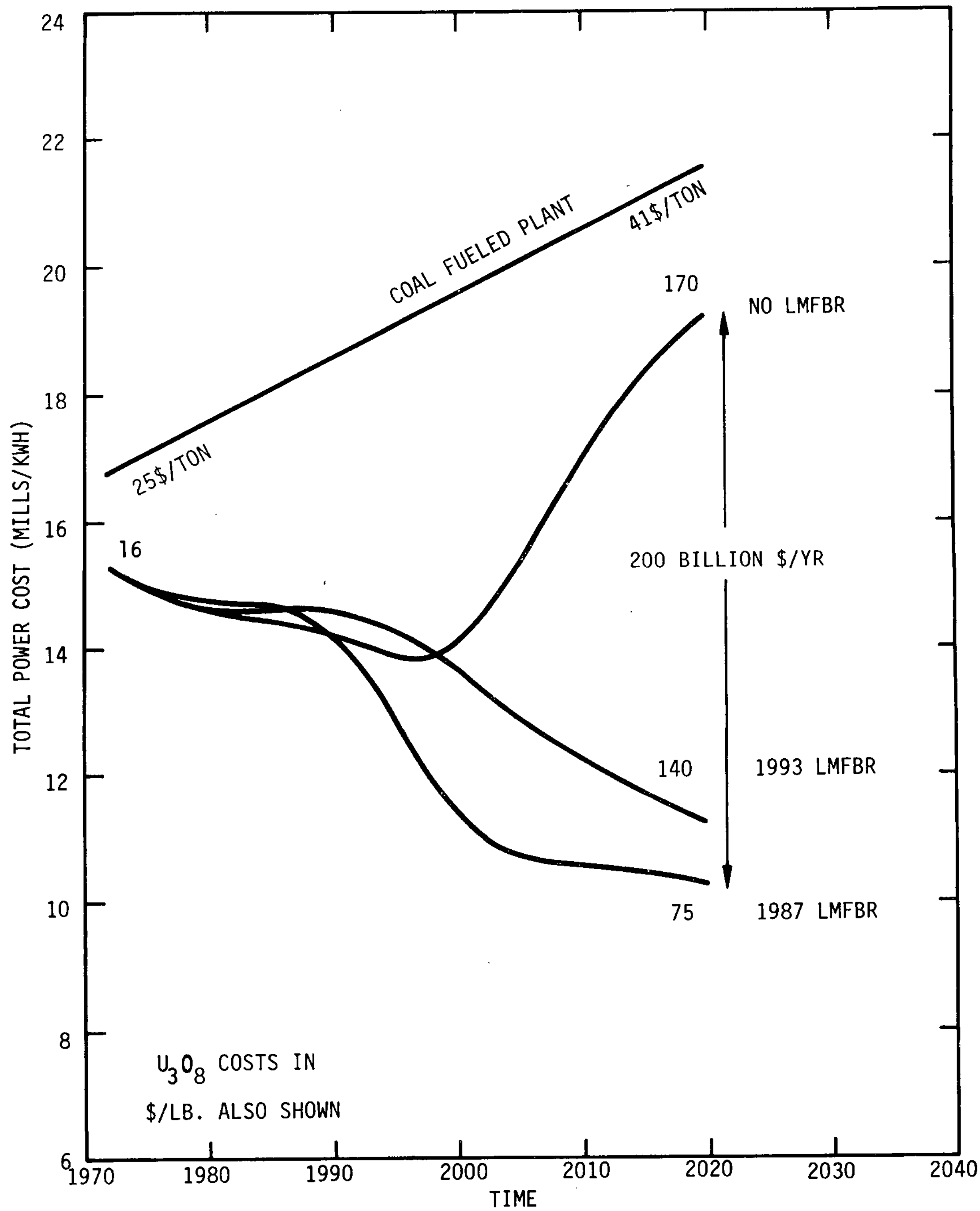
in that year. Note that an LWR-HTGR economy is capable of stabilizing the nuclear power cost, whereas the LMFBR with its increasing fuel supply, is capable of reducing it. Thus, even in the case where the LMFBR is not necessarily needed, it still reduces nuclear power costs by a substantial margin.

Consider next a case in which the LMFBR is definitely needed--i.e., the case of a small uranium supply and large energy demand. This is shown in Figures III F-28 and III F-29. The LMFBR then reduces nuclear power costs by about 9 mills/kwhr(e) in 2020, and this corresponds to cost reduction of about 200 billion dollars/year in the same year. Finally, consider the case of an LMFBR with a high capital cost, as shown in Figures III F-30 and III F-31. In this case, the LMFBR reduces nuclear power costs by about 3 mills/kwhr(e) in 2020 and thereby produces a saving of about 50 billion dollars/year. The plutonium-burning LMFBR is not built in the later years in this case. This is because it is more economical to burn the plutonium in a plutonium-loaded LWR, since the capital cost of this reactor is considerably lower.

Average nuclear power costs in 2020 for various combinations of energy demand, ore supply, and LMFBR capital cost are shown in Table III F-11. In general, nuclear power costs without the LMFBR are about 43% higher than with the LMFBR.

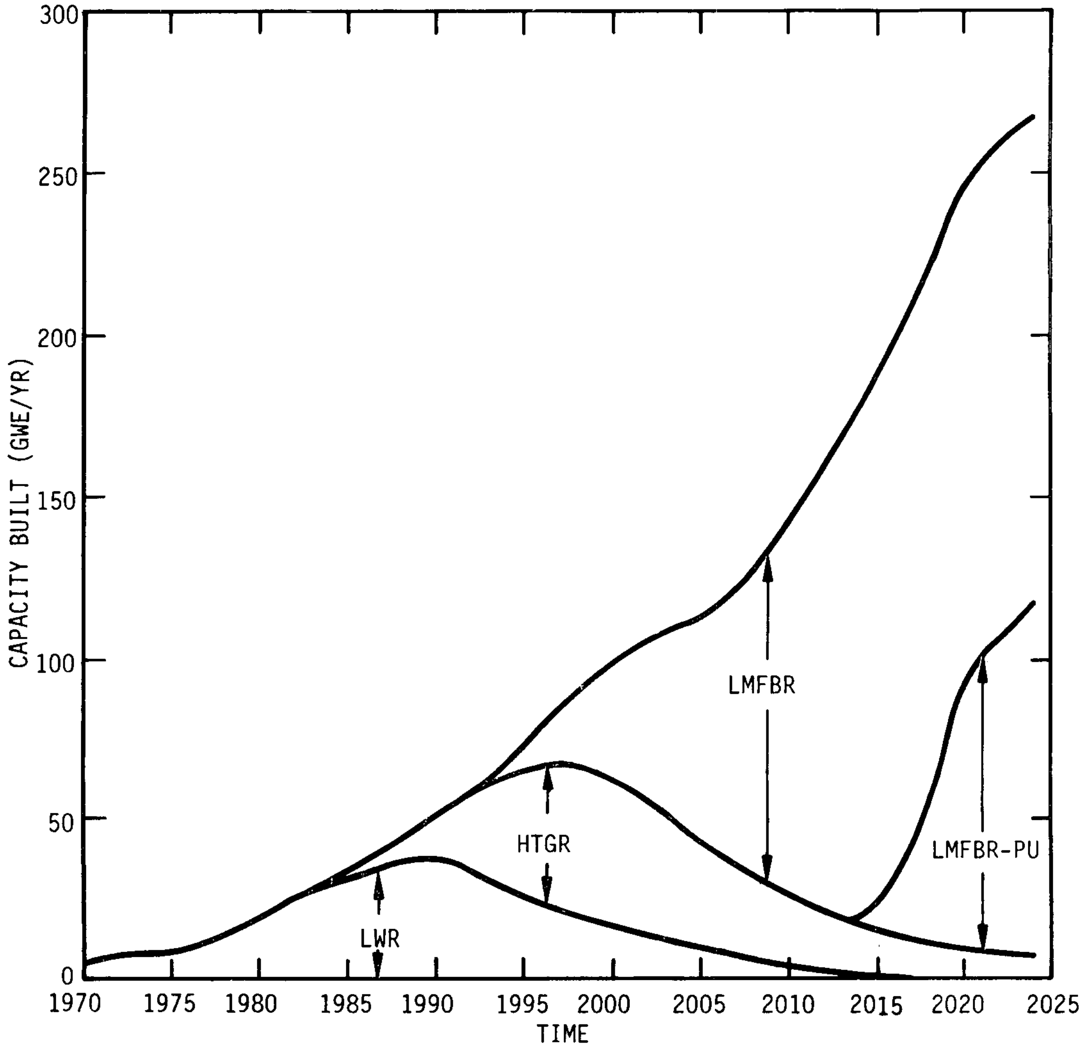
Figures III F-32 and III F-33 show the amount of U_3O_8 and separative work required as a function of the energy demand and the LMFBR introduction date. It is clear from these figures that delaying the LMFBR increases the requirements for both items to an excessive degree. In particular, delaying the LMFBR increases the requirement for U_3O_8 by approximately 0.2 million tons of U_3O_8 per year of delay, and similarly increases the requirement for enrichment capacity by almost 5 million SWU/year per year of delay.

Now let us turn our attention to possible advanced power sources. Many critics of the LMFBR view the possible commercialization of an advanced power source during the first decade of the next century as pursuasive and even conclusive evidence that the development of the LMFBR is not needed. The miniscule cost for fuel--water for fusion and sunlight for solar--they argue, will more than make up for the higher capital costs of these advanced power sources. As a result of these contentions, a sequence of calculations were made to evaluate the effect of an advanced power source on the LMFBR benefits stated above.[39] As a by-product, the benefits associated with the advanced power source itself were also obtained. Since design and cost data for solar and fusion sources are quite speculative, the forecasting calculations were



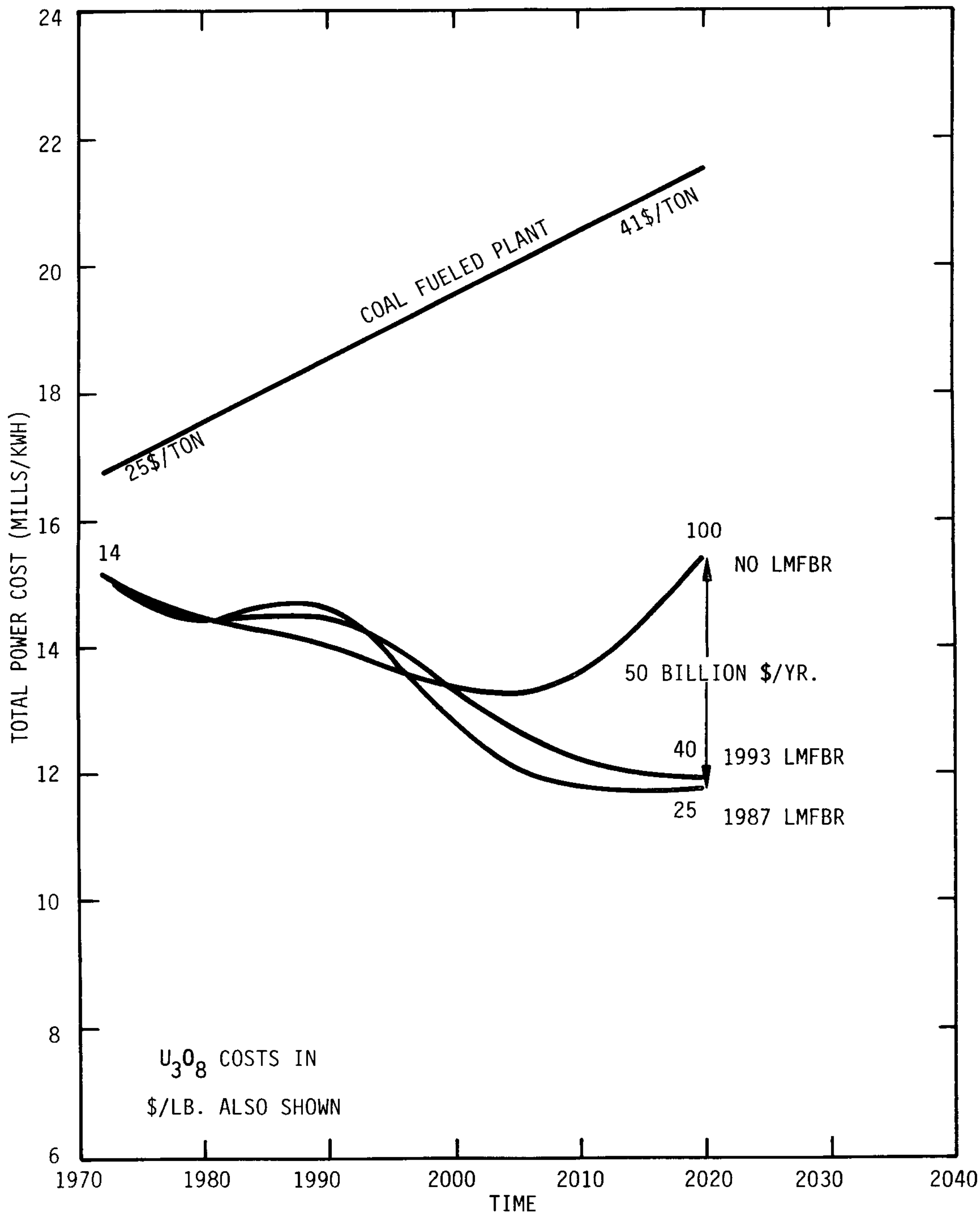
AVERAGE U.S. NUCLEAR POWER COSTS (1975-2025)
SMALL URANIUM SUPPLY AND LARGE ENERGY DEMAND

Figure III F-28



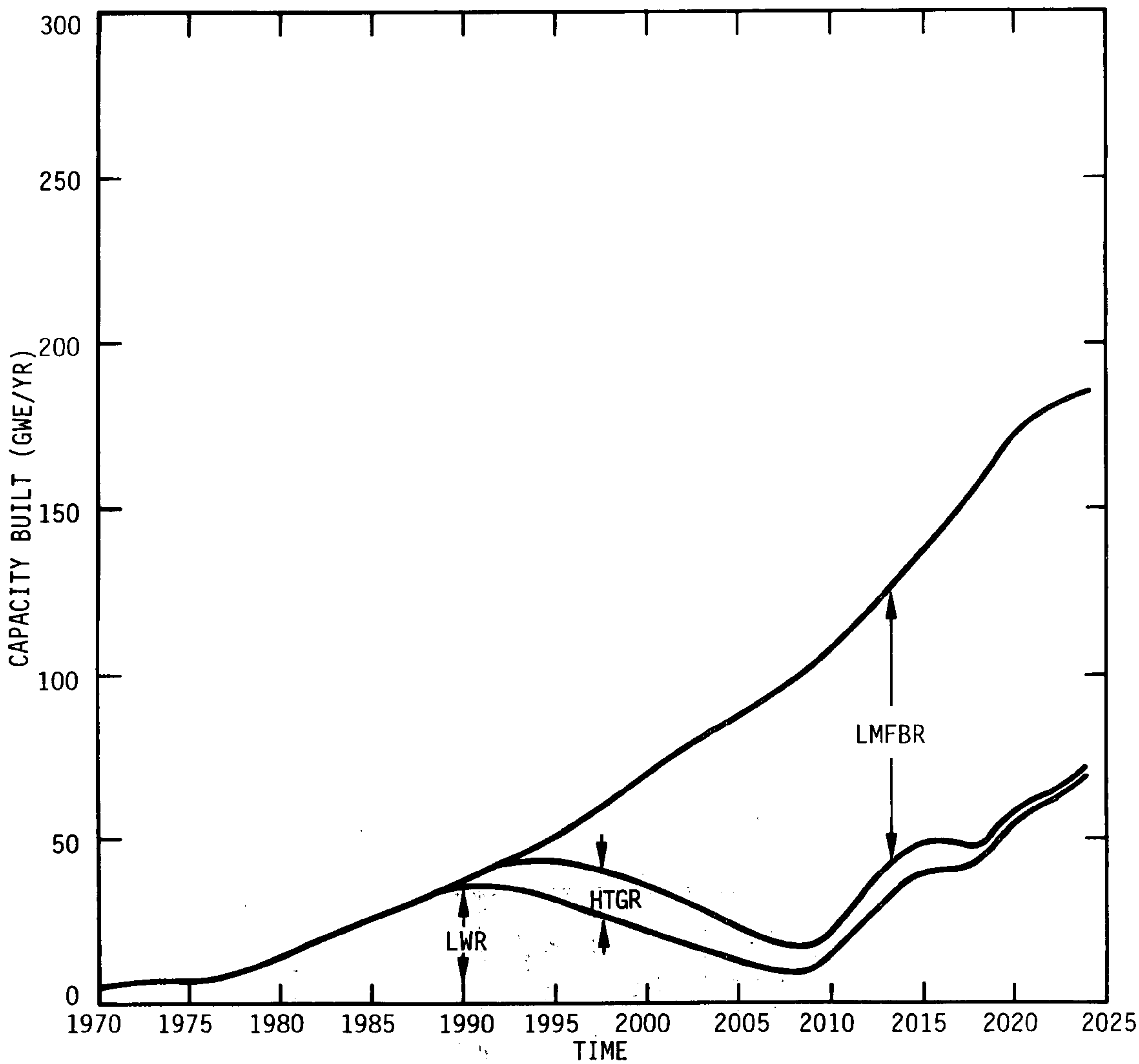
U.S. NUCLEAR POWER GROWTH PATTERN
SMALL ORE SUPPLY AND LARGE ENERGY DEMAND - 1993 LMFBR

Figure III F-29



AVERAGE U.S. NUCLEAR POWER COSTS (1975-2025)
HIGH CAPITAL COST

Figure III F-30



U.S. NUCLEAR POWER GROWTH PATTERN
HIGH CAPITAL COST - 1993 LMFBR

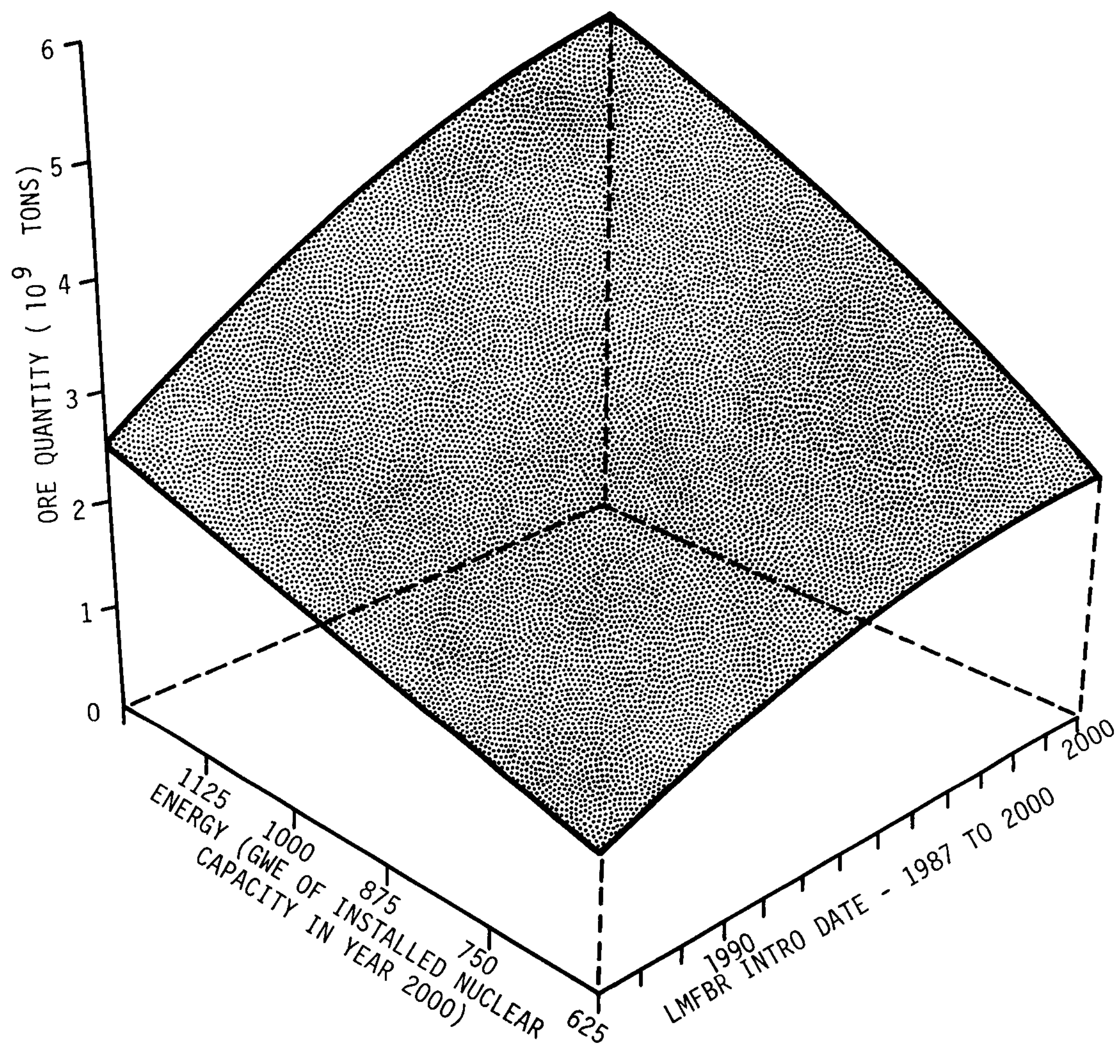
Figure III F-31

Table III F-11

AVERAGE U.S. NUCLEAR POWER COSTS IN 2020

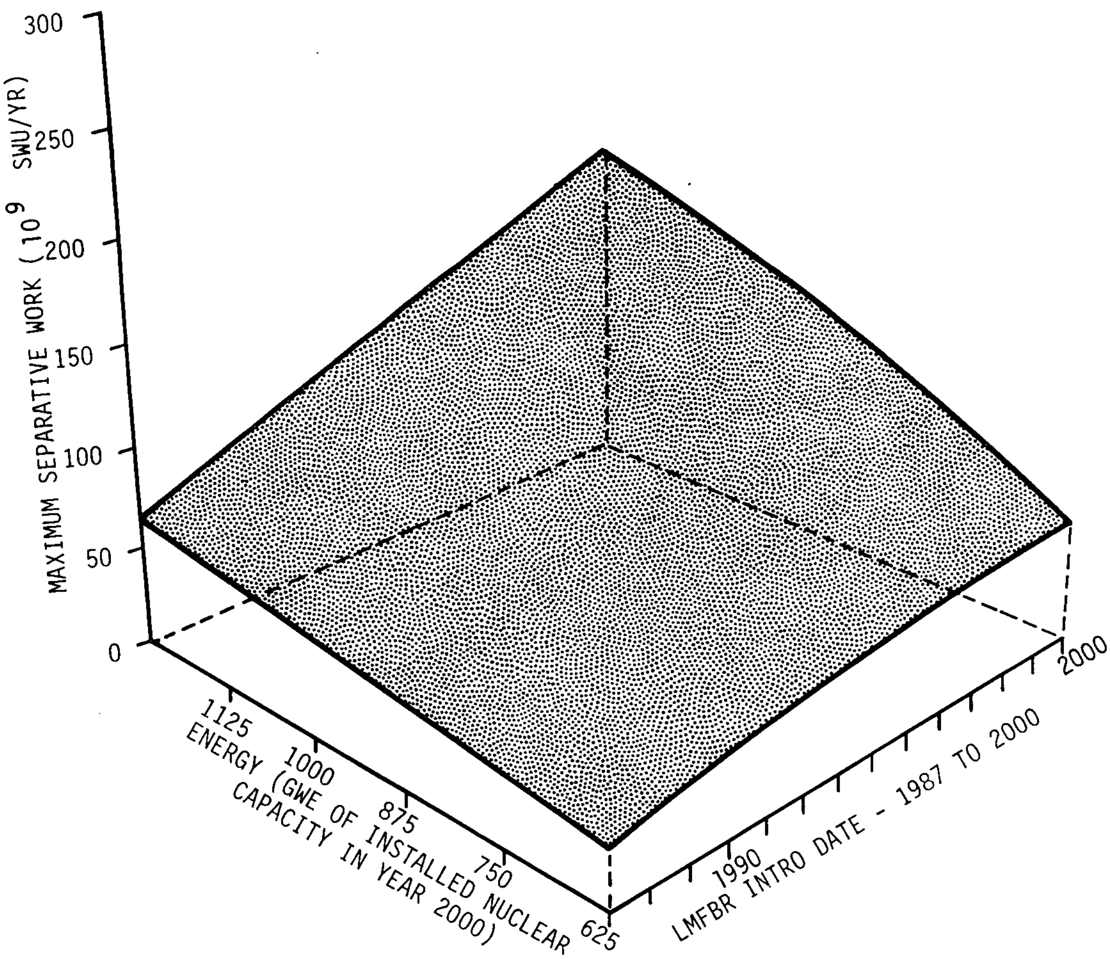
	LMFBR CAPITAL COST	B									H				
	U_3O_8 SUPPLY	B			S			L			B			S	L
	ENERGY DEMAND	B	S	L	B	S	L	B	S	L	B	S	L	B	B
LMFBR INTRODUCTION DATE	1993	10.2	9.9	10.5	10.5	10.2	11.2	10.1	9.9	10.2	11.9	11.6	12.3	12.2	11.8
	NONE	15.4	13.6	17.1	18.2	15.5	19.2	13.7	13.2	14.6	15.4	13.6	17.1	18.2	13.7

B = BASE S = SMALL L = LARGE H = HIGH



CUMULATIVE U_3O_8 VERSUS ENERGY DEMAND AND LMFBR INTRODUCTION DATE

Figure III F-32



MAXIMUM SEPARATIVE WORK REQUIREMENT VERSUS ENERGY DEMAND
AND LMFBR INTRODUCTION DATE

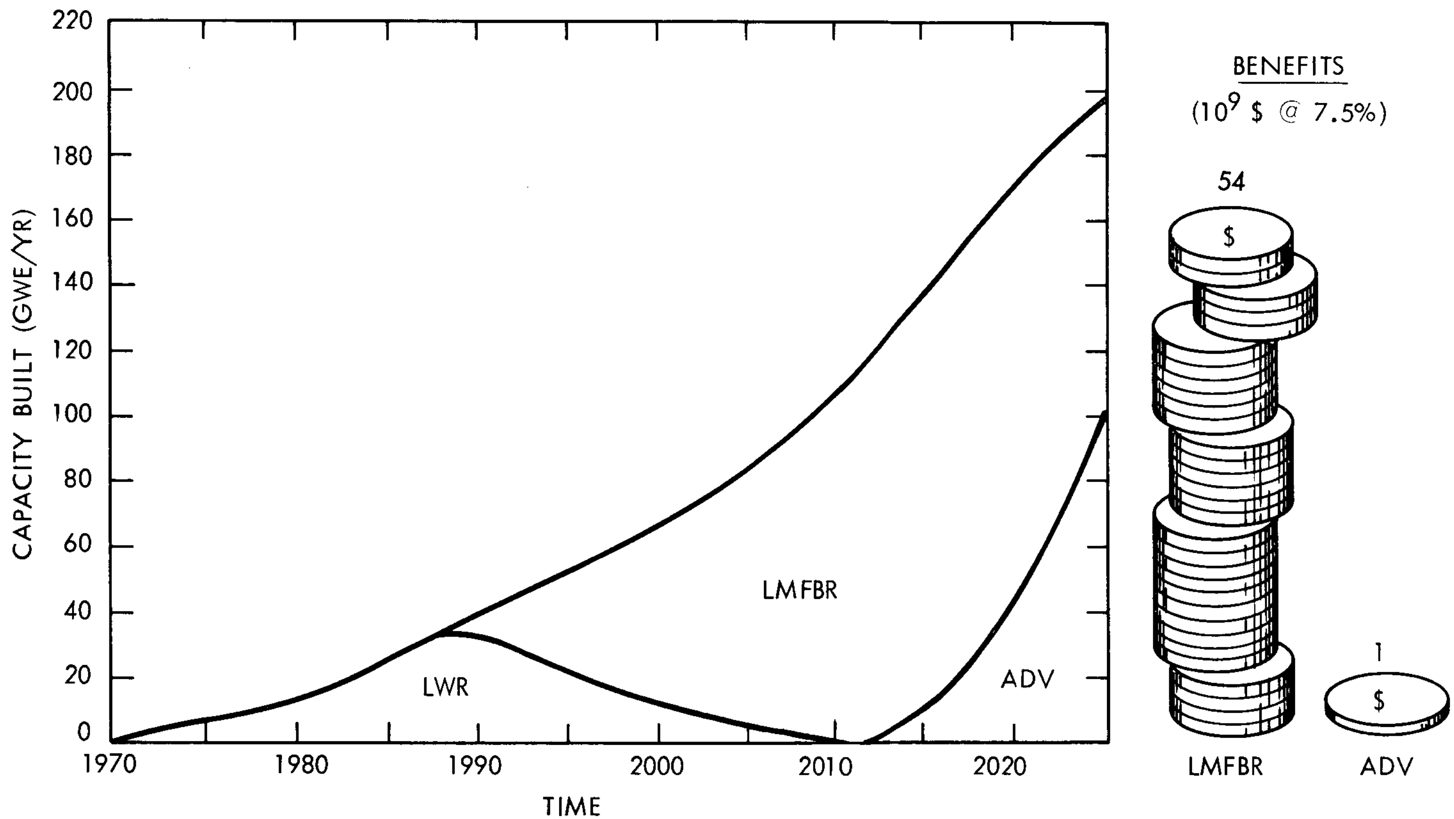
Figure III F-33

performed in a parametric fashion. An advanced power source of arbitrary design was assumed to be introduced in the year 2011 with a zero fuel cost, and with a capital cost of 50 $/kwe higher than the LMFBR. An advanced power source with a capital cost 25 $/Kwe higher than the LMFBR was also considered. These assumptions were quite arbitrary, and are definitely not meant to imply that the capital cost of an advanced power source will in fact be this low.

The nuclear industry growth pattern which is obtained when the advanced power source is allowed to compete freely with the LMFBR is shown in Figures III F-34 and III F-35. With a capital cost differential of 25 $/kwe, the advanced power source is able to take an ever increasing share of the market from the LMFBR, as shown in Figure III F-34. However, the benefits--from 1975 to 2041--associated with the advanced power source are about 1 billion dollars, while the benefits associated with the LMFBR over the same time span are about 54 billion dollars. The end of the planning horizon was extended from 2025 to 2041 in order to allow the advanced power source to make a significant market penetration.

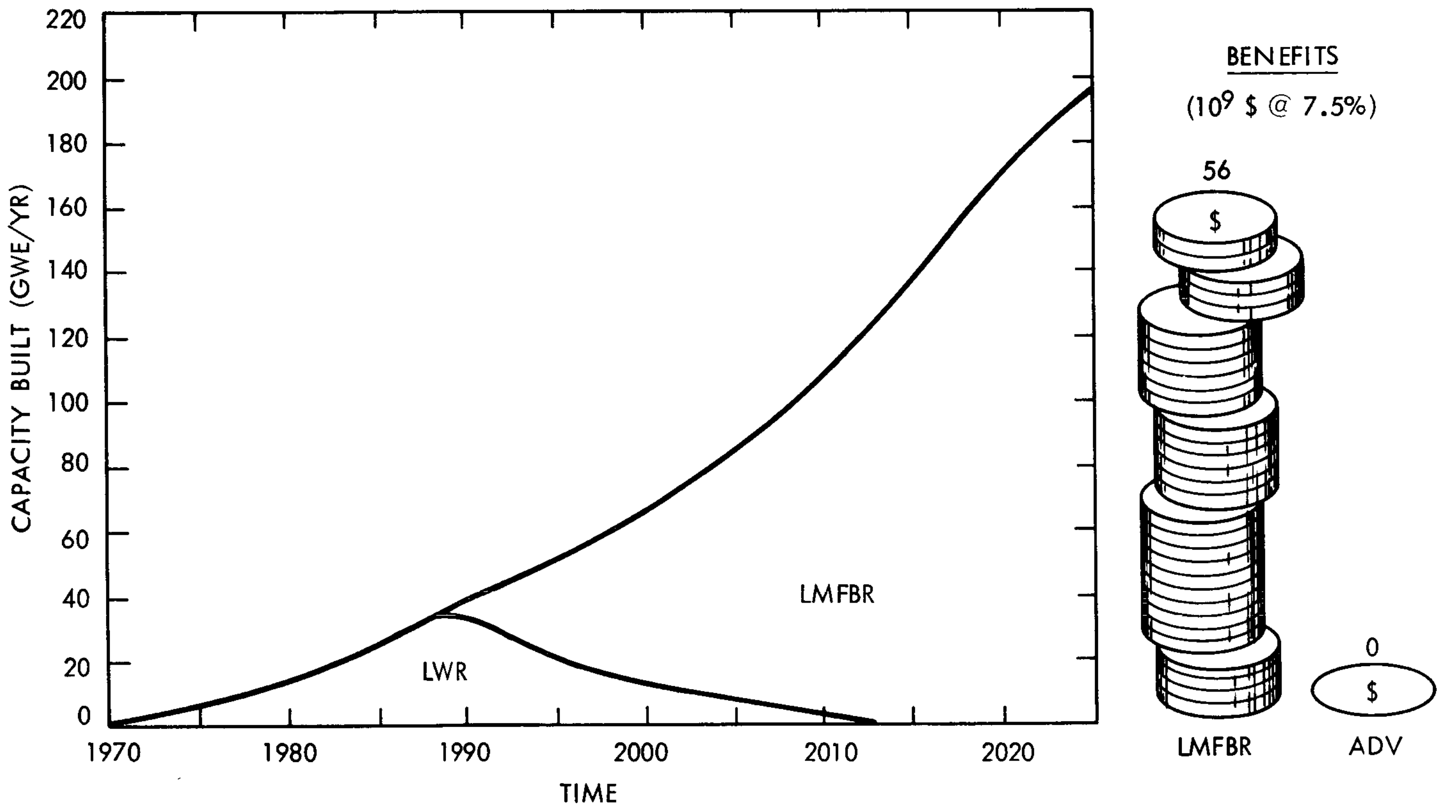
The reason that the benefits associated with the advanced power source are small is as follows. The fuel cost of the LMFBR is about 0.4 mills/kwh in 2020, and so the total power cost of the advanced power source is only slightly less than that of the LMFBR. Thus, the advanced power source is providing an insignificant reduction in total power cost in the distant future. The LMFBR, on the other hand, is providing a large reduction in power cost in the near future. With any real time value of money, the benefits obtainable from an advanced power source become inconsequential compared to those obtainable from the LMFBR.

The nuclear industry growth pattern which is obtained with a capital cost differential of 50 $/kwe between the advanced power source and the LMFBR is shown in Figure III F-35. In this case, the total power cost of the advanced power source is greater than that of the LMFBR, and consequently it is not built. As a result, the benefits associated with the advanced power source are zero, while the benefits associated with the LMFBR are 56 billion dollars. The discounted power cost over the planning horizon and the benefit associated with each power source are shown in Table III F-12. Note that the advanced power source benefits are significant only when the LMFBR does not exist, since the advanced power source was always built in this case. However, even in this case, the advanced power source benefits are substantially smaller than the LMFBR benefits.



NUCLEAR INDUSTRY GROWTH PATTERN WITH AN ADVANCED POWER SOURCE
AT A CAPITAL COST OF LMFBR + 25 $/kwe

Figure III F-34



NUCLEAR INDUSTRY GROWTH PATTERN WITH AN ADVANCED POWER SOURCE
AT A CAPITAL COST OF LMFBR + 50 \$/kwe

Figure III F-35

Table III F-12

EFFECT OF THE ADVANCED POWER SOURCE
DISCOUNTED POWER COSTS - 1975-2041
(10^9 $ @ 7.5%)

	With LMFBR	Without LMFBR	LMFBR Benefit
Adv. Power Source @ LMFBR + 25 $/kwe	338.7	393.2	54.5
No Adv. Power Source	339.4	419.0	79.6
Adv. Power Source Benefit	0.7	25.8	
Adv. Power Source @ LMFBR + 50 $/kwe	339.4	395.2	55.8
Adv. Power Source Benefit	0.0	23.8	

7. CONCLUSIONS

As national reserves of oil and natural gas decline, it becomes apparent that a new energy source will be required or we must be prepared to accept a significant decline in the quality of life. Insofar as electrical power is concerned, coal and nuclear energy are the only two options which meet the dual criteria of an available technology and an adequate fuel supply.

In this Section, we have shown that the LMFBR can have the following effects:

a. Free the electric power industry from a dependence upon depletable fuel supplies, which cannot be restricted by international political concerns;

b. Provide a large decrease in the production cost of electricity from nuclear power plants, primarily by reducing uranium ore and separative work requirements. In terms of undiscounted benefits it will reduce the cost of electrical energy by about one trillion dollars over the next fifty years, and will reduce the cost of electrical energy by 85 billion dollars per year in the year 2020 alone for base case conditions. Also for base case conditions uranium ore requirements are reduced by a factor of two and separative work requirements by a factor of four;

c. Early introduction of the breeder may reduce the capital investment required to develop the nuclear industry, since the investment in uranium mining, milling and uranium enrichment facilities saved by the breeder may be much greater than the added investment for breeder power plants;

d. The earlier the introduction of the breeder the greater the benefits. Society incurs a positive cost by adopting a wait and see attitude. A delay in the introduction of the LMFBR by seven years to year 2000 will cost 7 billion dollars, discounted at 10%. Discounted at 7.5% the delay costs 20 billion dollars. This additional cost--produced by higher cost electrical energy--is simply a foregone saving;

e. Provide economic benefits far in excess of the R&D costs required to develop the concept to the commercial stage.

We have shown that these considerations--while changed quantitatively--are not changed qualitatively over those presented in Section 11 of the PFES by changes in the major variables such as U_3O_8 price, energy demand, LMFBR capital cost, or by the introduction of an advanced power source.

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SECTION III G

HEALTH EFFECTS PROGRAM
- ACTINIDE ELEMENTS -

III G

4.7S HEALTH EFFECTS PROGRAM - ACTINIDE ELEMENTS

1. INTRODUCTION

The major issue regarding the health hazards of plutonium that was raised during the review of the PFES centered about the so-called "hot-particle" hypothesis which in essence postulates that the procedure of assessing plutonium health effect based on average organ doses is in error and that the health effects might be several orders of magnitude greater since the exposure is concentrated in limited areas of the lung in the vicinity of the "hot particles" with a much greater probability of cancer incidence than predicted using an average lung dose. In the opinion of the ERDA staff the evidence is overwhelmingly against the "hot particle" hypothesis and material attesting to this was presented at the Public Hearing on the PFES held on May 27-28, 1975.[1]

The Internal Review Board in its report to the Administrator[2] (see Section IV B) stated:

> "The outstanding issue is whether the hot particle hypothesis should be assumed as an additional degree of conservatism in projecting health effects from inhaled plutonium. In the judgment of the Board, this dispute turns upon peculiarly recondite matters of health physics and cannot be resolved within the confines of an environmental impact statement. It must await the verdict of the scientific community. The conclusions of the PFES appear to be based upon the considerable weight of current informed opinion and are therefore as adequate for decision-making as the state of the art will allow."

Section III G has been prepared to present the ongoing health effects program in the area of the actinide elements in order to amplify the record as presented in the PFES and the Public Hearing and to describe the efforts underway to improve the state of knowledge on the health effects of actinide elements including plutonium.

2. PROGRAM OVERVIEW

Research on the health hazards of plutonium and other alpha-emitting radionuclides (the actinides) was initiated with some of the first materials produced during and immediately following World War II. The results from those studies and others which followed have led to the establishment of radiation protection criteria for those radionuclides that are in use at the present time.

The current studies on the potential health effects of actinides are designed to better define the dose-response relationships for these radionuclides and to insure that the public health and safety is not endangered by the further development and use of nuclear technologies. The results from current studies will be utilized to further define these radiation protection criteria for man.

To accomplish this goal for nuclear and other developing energy technologies, it is necessary to (1) identify and characterize hazardous energy-related physical and chemical agents, (2) identify adverse human effects induced by these hazardous agents and develop an understanding of the basis for such effects, (3) develop methods for the early detection and diagnosis of energy-related health effects, (4) obtain quantitative data on dose-response relationships from epidemiological studies in humans and in several experimental animal species, (5) integrate the quantitative data from multiple animal species studies into predictive models that can be used to estimate human health risks under a variety of exposure conditions, and (6) develop improved modes of protection and remedial action. Research is currently under way in all of these areas for the actinide radionuclides.

The current research emphasis centers on evaluating health risks arising from exposures to the very low levels of radiation and/or radionuclides that may occur in work areas or in the general environment from the use of nuclear energy. Inhalation is considered the most significant exposure route for man and is receiving major emphasis in the research programs. In addition, the study of interactive effects occurring when biological systems are exposed to combinations of radionuclides and other hazardous agents is being given high priority.

The current emphasis on the study of low doses and dose rates dictates that delayed or late effects will be the primary experimental endpoints of importance. Both the potential somatic (e.g., cancer) and genetic effects are being evaluated. The need for a realistic assessment of health effects applies not only to on-line nuclear technologies but also to the array of new nuclear technologies currently in various stages of development.

Whenever possible, estimates of potential health risks are based on studies of humans who have been exposed accidentally, occupationally, or for other reasons to alpha-emitting radioactive isotopes (e.g., radium dial painters). It is also essential to obtain information on the metabolism and disposition of radionuclides generated and/or utilized in nuclear technologies as the basis for estimating the internal dose to critical organs for these hazardous materials whenever the opportunity arises.

However, due to extensive safety precautions which resulted from early recognition of the potential toxicity of these materials, opportunities for the study of exposed human populations have been limited and the studies are generally lacking in adequate control of important variables. Thus, the development of useful predictive models for man must rely heavily on research utilizing experimental animals. Whenever possible, the animal experiments are related to known radiation effects in man to provide more confidence in the extrapolation of the data to man. For example, the effects of plutonium deposited in the skeleton of experimental animals has been related to the effects likely to be observed in humans by comparison with the known effects of radium deposited in the skeleton of man by use of the following assumption:

$$\frac{\text{Toxicity of radium in man (known)}}{\text{Toxicity of plutonium in man (unknown)}} = \frac{\text{Toxicity of radium in experimental animals (known)}}{\text{Toxicity of plutonium in experimental animals (partially known)}}$$

While there are limitations in this type of extrapolation, it does provide a base of human data on which to make the extrapolation. However, at this time the direct comparison of effects in organs other than bone in this fashion is not possible due to a lack of data from man.

In addition, animal studies provide important information on the manner and degree to which the dose-response relationship may be affected by various modifying factors; they also provide detailed information on the kinetics and mechanisms of radionuclide metabolism. Interspecies comparisons are made with both short-lived and long-lived experimental animals, and the information is compared with observations on man in terms of the nature, severity, and time of appearance of the biological effects.

Since no single experimental animal is a sufficient model for man, several species must be used and experimental conditions sought which make possible risk estimates for human populations. By using an interspecies comparative approach, insights are gained into species similarities and differences with respect to sensitivity to hazardous agents, patterns of response, metabolism of internally deposited radionuclides, and organs at particular risk. The use of several species of laboratory animals for the establishment of dose-response relationships provides a greater degree of confidence when establishing exposure limits for man. While short-lived species (e.g., rat, hamster, mouse) are useful and essential for many types of studies, it is essential that studies be conducted in other species with longer lifespans (e.g., dogs).

The dose response studies to establish potential health risks are supplemented by supportive research of several types. Research on the pathophysiology of disease induction helps to define the complex sequence of biological events leading to overt clinical symptoms in the exposed organism and to clarify the nature of any functional impairments. Molecular and cellular studies elucidate mechanisms and consequences of damage and also determine protective mechanisms that may function in the animal. Other studies develop improved methods for the early detection and diagnosis of abnormalities induced by hazardous agents, including the development of nuclear medicine techniques which permit lesions to be detected and function to be assessed in many organ systems. An additional effort of high priority is concerned with developing effective means of protecting exposed individuals against serious injury and with facilitating recovery in persons exposed to radiation and/or radionuclides.

3. PROGRAM DESCRIPTION

A. HUMAN STUDIES

In order to assess human health risks properly, the magnitude of the dose of a hazardous agent must, if possible, be quantitatively correlated with the magnitude of the biological effect in man. It is then possible to devise predictive models with which one can calculate estimates of risks or hazards for different levels of human exposure. Predictive models are essential for setting and evaluating human exposure limits, for establishing guidelines with respect to the containment of hazardous agents, and for purposes of making cost/risk/benefit analyses used in long-range planning. The development of an adequate predictive capability requires a comprehensive program of research that includes human epidemiological studies. A number of these types of studies are under way in order to obtain the maximum amount of information possible on the effects of alpha-emitting radionuclides on man.

An epidemiologic study has been initiated on the follow-up of plutonium workers in six major ERDA contractor facilities. These are the Hanford, Los Alamos, Mound Laboratories, Oak Ridge, Rocky Flats and Savannah River Plants. Data will be accumulated on the incidence of disease in life and as a cause of death in active and separated employees. A comparison is intended between plutonium workers with detectable plutonium deposition, exposed workers with no record of detectable plutonium deposition, and plant employees who have not been exposed to plutonium. The former will represent the primary study group and the latter two, the comparison groups. Suitable populations for study will be developed at each facility, and uniform methods will be applied at the various facilities so that the resulting data can be pooled for analysis. The total population of workers in the study, including controls, may approximate 12,000.

The detailed follow-up examination of a more limited group of plutonium workers exposed during the Manhattan Project and at the Los Alamos Scientific Laboratory will be continued. The original group of 27 workers studied has been expanded to 250. A more extensive medical, radiological and health physics examination is provided to these individuals than is possible in the epidemiologic study described above.

The Transuranium Registry, operated by the Hanford Environmental Health Foundation, has continued to collect and analyze tissues from autopsies on workers potentially exposed to plutonium in ERDA facilities. Valuable data on the distribution of plutonium in various organs of the body have been developed in the study. In most of the autopsies the highest concentrations were found in the tracheobronchial lymph nodes, lung and liver. The number of identified transuranium workers as defined by the Registry was doubled during the past year. The analysis of plutonium in tissues obtained in the Registry program is performed at Pacific Northwest Laboratory.

Radioanalysis of plutonium in tissues obtained from autopsies performed on members of the general population is carried out at the Los Alamos Scientific Laboratory and at the Pacific Northwest Laboratory. At the Los Alamos Scientific Laboratory the principal geographical sources of autopsy tissues, with the number of cases under study (in parentheses), are as follows: Augusta, Georgia (79); Chicago, Illinois (33); Denver-Boulder, Colorado (295); Erie, Pennsylvania (182); Los Alamos, New Mexico (366); and New York City, New York (36). All tissues analyzed at Pacific Northwest Laboratory were obtained from the Richland, Washington, area. This program monitors levels of plutonium in tissues of the general population, both close to and at a distance from plants where plutonium is handled. These studies also provide information on the quantity of plutonium deposited in man via fallout resulting from the atmospheric dispersion of plutonium primarily as a consequence of the atmospheric nuclear weapons testing programs conducted by several nations prior to the 1963 Test Ban Treaty. In addition, late excretion patterns of plutonium in man have been investigated and a more rapid rate of excretion was found than presently accepted models would predict about 30 years after deposition.

The investigation of effects of radium in persons who incurred deposition as dial painters, chemists or medical patients is conducted by the Center for Human Radiobiology at Argonne National Laboratory. Of 3803 documented cases of such exposure, complete studies have been made on 1572 individuals. Malignant bone tumors (54 observed) and carcinomas of the mastoid and paranasal sinuses (27 observed) are attributed to the radium deposition. All bone tumors were recorded prior to 1969 while 6 cases of mastoid carcinoma have been reported since then. Studies of the relative biological effectiveness and/or the pattern of deposition in bone of Ra-224 are being conducted.

The ERDA Health and Mortality Study conducted by Dr. Thomas F. Mancuso of the University of Pittsburgh in collaboration with groups at the Oak Ridge, Hanford and Mound Laboratories facilities has continued its analysis of mortality patterns in the Hanford, Washington, nuclear workers. The relationship of levels of exposure to longevity is being explored and the study is being expanded to include information pertaining to the internal deposition of radionuclides. Collection of data from death certificates on deceased workers and their non-occupationally exposed siblings soon will be advanced sufficiently to permit analysis of the data on the large population of Oak Ridge workers (104,000) and their sibling controls (40,000).

At the University of Denver, a study continues of the chromosomal aberrations in the circulating lymphocytes of humans exposed to ^{222}Rn and ^{239}Pu. The number and kind of aberrations are compared with the length of time and type of exposure to these radionuclides.

ERDA contractors at St. Mary's Hospital in Grand Junction, Colorado, have developed cytological techniques for the identification of abnormal lung cells in human sputum. In a continuing surveillance effort, these techniques are being used to detect precancerous lesions in the lungs of 3500 uranium miners. Investigators at New York University are conducting measurements to determine how levels of radioactive lead-210 in the skulls of uranium miners correspond with the duration and degree of their exposures to radioactive mine air.

These studies currently provide valuable information on the assessment of the many variables governing the relationship between deposited alpha-emitting radionuclides and observed morbidity and/or mortality parameters. However, to a considerable extent meaningful data will be dependent upon the acquisition and radioanalyses of body tissues obtained at autopsy. Furthermore, in those studies in which morbidity is being followed, observations of appropriate endpoints (e.g., various types of cancer) must await the potential development of such diseases with time and determine their incidence and time of appearance in comparison with similar data from appropriate control populations. Although the radium population has either died or attained advanced age, it must be recognized that at present only the earliest plutonium workers are now approaching middle- and advanced age following exposure to significant levels of plutonium about 30 years ago. While information will be forthcoming on a continuing basis and summaries of data and estimates of its meaning prepared on a periodic basis, it undoubtedly will be 10 to 20 years before adequate data from sufficient numbers of persons will be available to formulate definitive conclusions and/or relationships.

Since the human epidemiological studies will never adequately define in a controlled manner all of the many factors which contribute to and ultimately dictate the potential health effects caused by the deposition of these radionuclides, extensive toxicological studies in experimental animals are being conducted.

B. ANIMAL STUDIES

1. General

The primary purpose of animal studies with internally deposited radionuclides is to help develop, qualitatively and quantitatively, a firm biological basis for assessing the risk to man associated with the exposure to radioactive materials. The research program consists of studies of the metabolism and toxic effects of radionuclides in experimental animals which can be compared with the results of epidemiological and metabolic studies on man. The animal work consists of carefully controlled laboratory experiments in which the metabolism, dosimetry and toxic effects are investigated in a variety of mammalian species with a view to understanding the comparative toxicity and metabolism in sufficient detail to reliably extrapolate to man, using appropriate mathematical modeling suitably tested in experimental animals and man.

The metabolic, dosimetric and toxic effects studies in animals take into account varying routes of exposure such as inhalation, ingestion, intravenous or intramuscular injection, etc., different chemical and physical forms of nuclides, age of the animals, specific metabolic traits of the animals, and the particular suitability of selected animals as models for physiological and pathological processes in humans. The purpose of metabolic studies is to identify the factors influencing localization of radioactive materials in organs, tissues and cells. The purpose of the dosimetric and toxic effects studies is to understand the types, mechanisms, and degrees of damage in order to assess the biological hazards resulting from intake of radionuclides. Collectively the research program is designed to assess the severity and the nature of the biological effects from internally deposited alpha-emitting radionuclides.

To obtain statistically valid data on late somatic effects, life time observations on large groups of animals exposed to graded doses of radionuclides are required. These studies have utilized several species of rodents (short-lived model) and the dog (long-lived model). Since the rodent and the dog are known to exhibit important differences with respect to metabolic patterns and organ function, metabolic studies are in progress on a smaller scale in two other short-lived species (i.e., the hamster and the mouse) and in two other long-lived species, miniature swine and subhuman primates. This comparative multispecies animal approach allows data to be extrapolated to man with greater confidence than would otherwise be possible.

The major concern, from an occupational and from a public health standpoint, is the assessment of risks that result from exposures to low levels of radiation. This program is concerned with accumulating quantitative data on late somatic effects, particularly the incidence of cancer. Since inhalation is the most common route for intake of transuranium radionuclides in man from nuclear energy operations, exposure of animals via the inhalation route is emphasized. However, in general populations uptake via the gastrointestinal tract may also be important and work continues with this exposure mode. The response after injection of radionuclides is also studied, since this provides the opportunity to deliver selected doses in well characterized forms, and to study the comparative metabolism and effects of various nuclides.

Since it is not possible to conduct comprehensive studies of all radionuclides of interest under a wide variety of conditions, emphasis is placed on the study of those radionuclides which are representative of a number of radioisotopes and/or which are expected to be of importance in developing technologies. Alpha-emitting radionuclides under intensive study now include, among others, various uranium and transuranium elements (principally isotopes of plutonium, americium, and curium), radium isotopes, and radioisotopes associated with uranium mining (radon and its radioactive decay products). Studies of inhaled radionuclides are conducted primarily at the Battelle Pacific Northwest Laboratory and at the Inhalation Toxicology Research Institute; injected radionuclides are studied at the Los Alamos Scientific Laboratory, the University of Utah, the University of California at Davis, the University of California at Berkeley, the Argonne National Laboratory, and the New York University; ingested internal emitters are being studied at the Pacific Northwest Laboratory and the University of California at Davis; the incorporation of radionuclides from puncture wounds is studied at Colorado State University.

The results of animal research provide information required in support of development decisions for various nuclear energy options, scientific information needed in the process of technology development, review of standards and regulatory aspects, and contribute towards a better scientific and public understanding of health risks associated with the use of nuclear energy. The information developed from this spectrum of studies on the effects of internally deposited radionuclides in man and experimental animals have been utilized to establish reasonable exposure guidelines for man. The emphasis of the current research is to provide information for the refinement of these guidelines either upward or downward and to provide positive answers to the significant questions that have been raised relating to potential unique dosimetry and toxicity problems from internally deposited radionuclides.

2. <u>Metabolism and Effects of Alpha-Emitting Radionuclides</u>

The distribution of plutonium within the body is markedly influenced by its physicochemical form and route of entry into the body. Studies conducted at the Argonne National Laboratory, the Pacific Northwest Laboratory and the University of Utah, have demonstrated that exposure of rodents and dogs to relatively high doses of plutonium by inhalation or injection results in an increased incidence of tumors in the lung, liver, and bone, with the target organ being dependent on the route of exposure and the eventual distribution within the body. The current research effort to determine the risk of exposure to plutonium is directed toward an understanding of the factors and events which lead to this tumor formation and to the identification and quantitation of the biological effects of inhaled, injected, or ingested plutonium at low exposure levels extending down to the equivalent of presently accepted body or organ burden limits for occupationally exposed humans. The influence of age at exposure and metabolic disturbances of the animal on the toxicity of plutonium are also under study.

Aerosols of alpha-emitting radionuclides that may be inhaled by man can be broadly classified as being relatively soluble and insoluble. Upon inhalation, insoluble aerosols remain in lung tissue for long periods of time, irradiating cells in the locality of the particles. The resulting radiation exposure is both very nonuniform and highly variable depending on the number of particles, and the degree of translocation both on a micro and macro scale within the lung.

There are three major and complementary programs which are designed to assess the degree of risk associated with the inhalation of particles of plutonium dioxide. At the Inhalation Toxicology Research Institute a series of exposures of rodents and beagle dogs is under way using single sized (monodisperse) alpha emitting particles; the experimental design includes variability in particle number, size, and specific activity. These studies should determine the comparative risk of pulmonary neoplasia associated with nonuniform vs. uniform distribution of radiation dose to the lung tissue.

A second experiment relating to the significance of the degree of homogeneity of the radiation dose to the lung is being conducted at the Los Alamos Scientific Laboratory, where it has been shown that Syrian hamsters retain specific numbers of particles containing plutonium of varying specific activity per particle in the pulmonary capillaries following injection into the jugular vein. While these exposures differ from inhalation exposures in that translocation to lymph nodes does not occur and the particles remain relatively fixed in location, they do permit precise quantitation of macro- and microdosimetry, and provide one basis for estimating the carcinogenic risk from varying numbers and activities of alpha-emitting particles and the resulting difference in dose distribution.

Studies in which dogs were exposed to polydisperse aerosols of $^{239}PuO_2$ and $^{238}PuO_2$ are being conducted at the Pacific Northwest Laboratory. Past studies have shown that relatively high lung burdens of inhaled Pu-239 dioxide result in lung tumors. Similar studies with inhaled Pu-238 dioxide have shown that the skeleton may be the critical organ for this plutonium compound since osteosarcomas (bone tumors) were observed at a higher incidence than lung tumors were.

A major series of plutonium inhalation studies in beagle dogs was initiated nearly six years ago at this laboratory in which the exposure levels were extended to lower initial lung burdens which approximate the occupational exposure limits for inhaled plutonium. These studies at the Inhalation Toxicology Research Institute, Los Alamos Scientific Laboratory and Pacific Northwest Laboratory will provide information concerning the relative importance of particle size, particle activity, radiation dose and identification of the cells at risk in the induction of lung cancer from inhaled alpha emitting particulates, and they extend the dose-response relationship considerably below those previously studied.

Soluble alpha-emitting aerosols (e.g., nitrates) are also likely to be inhaled in certain stages of the fuel cycle. Plutonium nitrate is expected to be a major form of plutonium to which workers involved in fuel reprocessing might potentially be exposed. Limited studies exposing small animals to aerosols of plutonium nitrate resulted in the induction of both osteosarcoma and lung cancer. Accordingly, low level inhalation exposures of rodents to plutonium nitrate are being conducted at the Pacific Northwest Laboratory and Inhalation Toxicology Research Institute, and similar exposures of beagle dogs are being studied at the Pacific Northwest Laboratory. These studies, utilizing both plutonium-239 and plutonium-238, complement the studies of the oxide compounds of these radionuclides discussed above.

In addition to the plutonium studies indicated above, range-finding studies of the effects in rodents of inhaled oxides and nitrates of americium and curium are under way at the Inhalation Toxicology Research Institute and the Pacific Northwest Laboratory to determine the desirability and necessity for designing appropriate detailed studies in large animals (dogs, miniature swine, or primates). The importance of these studies is related to their prevalence in the nuclear fuel cycle, to their use for better defining the mechanisms and critical factors governing the carcinogenicity of the alpha-emitting radionuclides, and to a variety of beneficial purposes for which these radioisotopes are used, such as thermoelectric sources (e.g., Pu-238, Cm-244 in heart pacemakers and navigational equipment) and ionization sources (e.g., Am-241 in smoke detectors), all of which involve the possibility of occupational and environmental exposure.

Because of the possibility of chronic or repeated human inhalation exposures to very low plutonium levels, studies in rodents and dogs subjected to chronic exposure to plutonium aerosols were recently initiated at the Inhalation Toxicology Research Institute.

The isotopic composition (specific activity) and particle matrix of plutonium produced in nuclear power plants is considerably different from that of "pure" Pu-238, important for space nuclear power sources, and from that of Pu-239, important for weapons, which have been used in past studies. Plutonium nuclear reactor fuels may be intimately incorporated with uranium, which will comprise most of the particle mass. In addition, the association of Pu-containing aerosols with other elements, particularly sodium, might be expected in the LMFBR in the event of an accident, thereby presenting the possibility of a combined risk of inhalation of plutonium and sodium aerosols. Studies at the Pacific Northwest Laboratory and the Inhalation Toxicology Research Institute are investigating mixed oxides of uranium, plutonium, curium and americium, and sodium and plutonium aerosols are under study at the Pacific Northwest Laboratory.

To complement these laboratory studies, samples of aerosols of mixed uranium and transuranium oxides typical of those utilized in reactor fuels are being collected and characterized from reactor fuel fabrication facilities as to their aerodynamic properties and chemical form. *In vitro* solubility studies are being conducted on the materials to determine their probable lung retention times in case of accidental exposure. These studies will be extended soon to include the exposure of rodents and sub-human primates to these aerosols to confirm their biological behavior. These studies will permit comparison between studies with well characterized laboratory aerosols formed under known conditions and studies utilizing aerosols likely to be encountered in accident situations.

These various investigations consist of a great many separate experiments. Some of these experiments have been in progress for several years; others have been initiated in the past year or two; a limited number are currently being initiated. Consequently the results will become available as data is published and assessments of the data are made over a continuum of time. It is reasonable to expect, however, that more complete metabolic data will be available within five years, that various aspects of the current studies relating to dose-effect relationships in rodents--including the comparative studies on uniform and non-uniform exposure of the lung--will be concluded within five to ten years, and that the majority of the present studies on long-lived species will be complete in ten to twenty years. This anticipated availability of data, however, does not pertain to any additional studies which, as a consequence of future findings or of future problem areas, may be initiated as the need arises.

Studies on the effects of alpha-emitting radionuclides deposited in the skeleton are being conducted at the University of Utah. Comparative tumorigenic effects of Pu, Am, Cm, Th, and Ra injected intravenously are being investigated in the beagle dog and in rodents. Since there is considerable human data on the induction of bone tumors (osteosarcoma) from the radium dial painters, these studies are designed to compare the effects of radium in the beagle dog with observed effects in humans, to compare the effects from other injected alpha-emitting radionuclides (primarily plutonium and other transuranium elements) in the dog with the effects from radium studies, and, therefore, to provide a basis for the extrapolation of their relative toxicity in dog to their relative toxicity in man. In order to increase the degree of confidence with which such extrapolations are made, it is necessary to understand the species characteristics and variables of bone dynamics as a function of age, the local bone dosimetry, cells at risk, and the histopathology of induced lesions. Studies of the behavior of radionuclides deposited in soft tissues, particularly the liver, are also important, and studies are being conducted to better define translocation rates between tissues. Mathematical models are being refined which relate radiation dose and dose-rate to cancer induction. Studies are in progress to determine the dose-response of these radionuclides at much lower doses corresponding to levels equivalent to occupational body burden exposure limits for plutonium in man. The rodent studies are expected to provide additional data within three to five years; the dog studies will be complete in fifteen to twenty years, although much data will become available prior to that time.

Although the mammalian gastro-intestinal tract discriminates strongly against most plutonium and transplutonium compounds, there is some absorption, depending upon the physicochemical form (e.g., isotope, soluble vs. insoluble, organically bound, etc.). Previous studies have shown that following gastro-intestinal absorption, the skeleton will accumulate the highest radiation dose; accordingly, injection studies are directly relevant to internal distributions which are characteristic of ingestion. Alpha-emitting radionuclides are also incorporated into skeletal tissue following inhalation when they are translocated from the tracheobronchial lymph nodes and lung. The absorption and translocation kinetics of ingested isotopes of plutonium, uranium, neptunium, curium and californium are being determined in studies at the Pacific Northwest Laboratory in order to more accurately predict the amount reaching critical tissues under a variety of physiological and environmental conditions. These ongoing studies provide information on a continuing basis and are expected to continue in one form or another for another five years or more.

At Lawrence Berkeley Laboratory the kinetics and distribution of ^{238}Pu and ^{241}Am at the organ and cellular level are under study in two subhuman primate species: rhesus and cynomologous monkeys. At New York University metabolic studies of ^{241}Am, ^{244}Cm and ^{210}Pb are underway in another subhuman primate, the baboon, and the kinetics and distribution of these radionuclides are being investigated. Studies at Colorado State University continue to evaluate intradermally injected plutonium (simulating wound contamination) and to determine its translocation and effects as a function of chemical form, anatomical site, and preventive measures.

3. Recovery and Treatment

Research is being conducted to develop effective and safe methods of preventing or reducing the toxic effects of plutonium or other radionuclides deposited internally by the use of special agents or procedures that accelerate removal and excretion of the radioisotope or decrease their absorption and, consequently, reduce the associated risk. The currently accepted treatment for plutonium and many other radionuclides deposited in the body consists of chelation therapy, possibly combined with bronchopulmonary lavage if the radionuclide was inhaled. Past studies have shown that the chelating agent diethylenetriaminepentaacetic acid (DTPA) readily binds to plutonium and related radionuclides in the blood to form soluble complexes that are readily eliminated via the kidneys. The calcium salt of DTPA is approved for investigational use in humans and is used to treat accidental exposures of man. However, the calcium salt has been shown to be embryotoxic in mice and, under certain conditions, can cause disadvantageous side effects. Studies at the Pacific Northwest Laboratory and the University of Utah have demonstrated that the zinc salt of DTPA is as effective as the calcium salt, is less toxic and can be chronically administered over prolonged time periods. Thus, research is now under way to develop the most effective therapeutic regimes for zinc DTPA.

While the current therapeutic regime utilizing calcium DTPA removes a variable percentage of the internally deposited radionuclide, its efficacy in removing plutonium and other radionuclides desposited in bone and skeleton is limited. Several approaches to overcome this limitation are being investigated. The first of these is the synthesis of new chelating agents with a higher degree of specificity and/or a greater solubility in lipids. Studies at the University of Utah are investigating the efficacy and toxicity of multi-heteromacrocyclic molecules synthesized at the University of California at Los Angeles. These compounds can shape themselves to the actinide ion to provide a very high level of specificity of chelation. The Argonne National Laboratory is investigating the efficacy of DTPA encapsulated into lipid materials prior to their administration in order to increase the entry of DTPA into the cell. The development of repository forms of zinc DTPA to provide chronic or continuous chelation therapy is also under investigation. Studies at New York University have shown that calcium DTPA is more effective in removing skeletally deposited Am-241 from the juvenile baboon as compared with the adult.

As inhalation is one of the most prevalent modes of exposure in accidents with nuclear materials and standard chelation therapy is relatively ineffective in removing inhaled materials, particularly if they are relatively insoluble, efficient therapy for inhalation deposition is needed. Bronchopulmonary lavage therapy which consists of flushing or washing the lung with physiological saline solution has been systematically evaluated in beagle dogs at the Inhalation Toxicology Research Institute, with an emphasis on the efficacy of the removal of the inhaled radionuclide and the safety of the technique. Current bronchopulmonary methods are effective in removing about 40% of the inhaled material from the lung. Methods to increase the efficacy of removal and to understand the factors responsible for variations in efficacy are under way. The efficacy of DTPA administered by inhalation rather than injection is being investigated at Pacific Northwest Laboratory.

In addition to evaluating the efficacy of therapeutic techniques in removing deposited radionuclides, studies are under way at the Pacific Northwest Laboratory and the Inhalation Toxicology Research Institute to evaluate the efficacy of these therapeutic techniques in reducing the incidence of biological effects. It is essential to recognize that the reduction in the body burden by therapeutic techniques may or may not proportionately reduce the biological consequences. Thus animals treated by chelation therapy and bronchopulmonary lavage are being observed to determine the efficacy of these techniques in reducing the biological effects.

The time period in which these several studies will be complete is difficult to estimate since it is impossible to prejudge the success or failure of any of the studies, or to indicate when the many variables involved will be characterized. It is expected, however, that initial results will be available within two to three years.

4. <u>Supporting Studies</u>

Studies of the pathogenesis and biological mechanisms of radiation damage are also essential to the development of radiation protection standards and the development of techniques to alleviate the biological effects. The toxicity studies described previously are providing information on the response to radiation in the intact animal. In order to understand these observed effects and extend the application of knowledge gained from animal experiments it is essential to understand the basic biological mechanisms that are responsible for these biological effects.

The hematopoietic system is known to be sensitive to the effects of ionizing radiation. Disturbances of production of both white and red blood cells has been observed following radiation exposure. These disturbances lead to a variety of diseases including septicemia, anemia and leukemia. Studies at Lawrence Berkeley Laboratory, Brookhaven National Laboratory, and Holifield National Laboratory as well as at a number of university laboratories involve an assessment of normal function of this system.

The immune system comprises the first line of defense of the body against infectious and malignant diseases and is sensitive to a number of chemical and physical agents. Studies at Franklin McLean Memorial Research Institute and a number of universities are focused on how the immune system functions and is perturbed. The role of immunosuppression and/or possible viral activation in the development of radiation induced tumors is under investigation at the Pacific Northwest Laboratory, the Argonne National Laboratory, the University of California at Davis and the Inhalation Toxicology Research Institute. These studies are utilizing animal models of radiation induced tumors developed from the results of the long-term toxicity studies.

Both the reproductive system and the developing embryo are sensitive to radiation which can induce sterility or a variety of disease states in the offspring. The Lawrence Livermore Laboratory and two universities are conducting studies of normal development. Studies at the Pacific Northwest Laboratory are examining the embryotoxic and teratogenic effects of prenatally administered plutonium, americium and curium.

Pulmonary injury and neoplasia development are well documented effects of inhaled alpha-emitting radionuclides at high doses in experimental animals. Studies are under way at the Pacific Northwest Laboratory and the Inhalation Toxicology Research Institute to determine the underlying mechanism of the damage. These include studies on the biochemistry of collagen synthesis in the development of pulmonary fibrosis and studies on the synthesis of pulmonary surfactant in normal and irradiated lung. The inflammatory response of the lung following radiation injury is being investigated and compared to the response of the lung to other types of injury. The role and function of the pulmonary macrophage in pulmonary clearance and in the pathogenesis of pulmonary disease is also under investigation. In order to better understand the development of pulmonary neoplasia and the cells at risk from inhaled radionuclides it is essential that additional information be obtained on the kinetics of the pulmonary cells. Studies on the turnover times of lung cells have been initiated.

The skeleton is a site for the eventual deposition of many radionuclides. Studies have shown that the critical cell for the development of bone-related tumors are located on bone surfaces. Thus one critical factor in interspecies comparison is the rate of bone remodeling for man and other species, and qualitative and quantitative studies of this nature are being conducted at several laboratories.

Studies are under way at the Argonne National Laboratory, the Los Alamos Scientific Laboratory and the University of Utah to develop an understanding of the chemical binding and subcellular localization of plutonium and other transuranium radionuclides. With a better understanding of the kinetics of transport and cellular binding a more rational approach to such factors as interspecies differences in the metabolism of these elements and their eventual removal from the body can be made. It has been shown that plutonium in the blood is transported by the iron binding protein transferrin. Studies have been initiated to determine how this protein releases plutonium into the liver and skeleton and how this mechanism might be precluded in order to prevent the deposition of the plutonium into these organs.

5. Genetic Studies

The previous discussion has addressed itself to research on the somatic effects of these transuranic radionuclides. Research on the genetic effects of these radionuclides has also been initiated. Although much of the work on genetic effects of radiation has employed external sources because of the greater precision of dosimetry, most of this work, especially that related to the mechanisms of mutation, is also directly applicable to radiation from internally deposited radionuclides such as the actinides. Research on the genetic effects of internally deposited radionuclides has been limited to those cases where specific questions relate to the properties of the radionuclide and/or the effects of its incorporation into the genetic material, or the effects of some specific radionuclide that may constitute a special occupational or environmental hazard.

While the deposition of plutonium and transplutonium elements in the gonads of mammals is very low (less than .1% of that in the blood) there is concern for the potential genetic effect of this deposition due to the densely ionizing alpha particles from these radionuclides. Studies to delineate the genetic effects, if any, of plutonium have recently been initiated at Argonne National Laboratory. This study is designed to determine uptake and retention coefficients for plutonium in the gonads, to determine the microdistribution of the dose within the gonads, and to assess any genetic damage by determining dominant lethal mutation rates and chromosome aberrations.

The Inhalation Toxicology Research Institute at Albuquerque, New Mexico is studying the relative biological effectiveness of external radiation sources and of internally deposited radionuclides, including transuranic elements, in producing chromosomal aberrations in liver cells. The relative effectiveness of a uniformly vs. non-uniformly distributed dose in causing chromosome aberrations is also being studied.

At the Inhalation Toxicology Research Institute rhesus monkeys were exposed to aerosols of $^{239}PuO_2$ in order to achieve a wide range of lung burdens. These monkeys are being studied to determine chromosome aberration rates in cultured blood lymphocytes at various times post-inhalation exposure. This study relates to the reported increase in chromosome aberrations in lymphocytes of occupational workers who accidentally inhaled plutonium. However, the external radiation exposure history of the workers complicates the interpretation of the chromosome aberrations.

C. SUMMARY

In summary, current research investigating the biomedical effects of inhaled and ingested alpha-emitting radionuclides, especially those of the transuranic elements, is being supported across a broad spectrum of disciplines and interests extending from acute sub-cellular effects studies to large scale long-term low-level toxicity studies in animals and to human epidemiological studies. These numerous efforts are expected to expand the existing large plutonium data base and are designed to provide information so that informed judgments can be made in a timely manner.

Although information from all of these studies continually will be accumulating, individual projects are expected to be completed over varying periods of time, extending from three to approximately twenty years depending upon the specific area of investigation. Ultimately, the aggregate results of these programs will provide a more definitive body of knowledge upon which to assess the biomedical effects in man of low-level exposure to the alpha-emitting radionuclides.

REFERENCES FOR SECTION III G

1. Public Hearing Record on the Proposed Final Environmental Statement (December 1974) for the Liquid Metal Fast Breeder Reactor Program, WASH-1535, Volume 1, Tab 4, pp 420-445; Volume 2, Tab 5.

2. Report to the Administrator on the Proposed Final Environmental Statement for the Liquid Metal Fast Breeder Reactor Program by the Internal Review Board, June 20, 1975, R. W. Fri, J. M. Teem, J. S. Kane, and S. W. Gouse.

SECTION III H

ALTERNATIVE LONG-TERM ENERGY SYSTEMS OPTIONS

INTRODUCTION

The Administrator of ERDA in his Findings on the LMFBR Program PFES[1] stated that:

> "The PFES amply demonstrates the need to continue research, development and demonstration of the LMFBR concept. There is no presently available or prudent alternative to this course of action. This technology holds the promise of an essentially inexhaustible source of energy to satisfy a significant share of this Nation's energy needs in the next century. While LMFBR technology is not the only technology which may be able to satisfy this objective, significant uncertainties concerning timely availability of the other major candidates, which are solar electric and fusion energy, make it risky and imprudent to discard the LMFBR Program on the basis of what we presently know. It is simply too soon to confirm with sufficient reliability that these alternate technologies will be available on time and in adequate quantity. It is speculative at this time that these options would be environmentally preferable to the LMFBR technology. Moreover, while I do not adopt any particular growth projection, including those postulated in the PFES, I cannot now discount the possibility that contributions from all three technologies will be desirable or needed to meet future energy demands. The possible needs are such, and the promise of energy from inexhaustible sources so great, that all three technologies must be pursued on a priority basis."

Since the LMFBR Program PFES (Section II of this Statement) was prepared, the Energy Research and Development Administration has been established. ERDA has a much broader charter in the energy research and development area than the Atomic Energy Commission and has the responsibility for the research and development of all promising energy production systems, non-nuclear as well as nuclear.

In the process of carrying out its responsibility in this area, ERDA has prepared "A National Plan for Energy Research, Development and Demonstration," ERDA-48,[2] which is "designed to achieve solutions to energy supply system and associated environmental problems in (a) the immediate and short-term (to the early 1980's); (b) the middle term (the early 1980's to 2000); and (c) the long term (beyond 2000)."[3]

The two technologies which the Administrator singled out as major candidates in addition to the breeder to provide an essentially inexhaustible source of energy to satisfy a significant share of the Nation's energy needs in the next century were solar electric and fusion. These have been classified along with the breeder as "'Inexhaustible' Sources for the Long Term" (See ERDA-48, p. S-6.).

Since ERDA has developed a comprehensive overall energy program plan, it is appropriate to update the information provided in the PFES with information on the research, development and demonstration programs planned by ERDA and described in ERDA-48 to explore the potential of solar and fusion energy and attempt to bring their promise to fruition. Section III H.1 describes the solar electric energy program and Section III H.2 describes the fusion energy programs which are carried out in two discrete programs. As described in Section II, 6A.1.6 one of these programs involves the use of magnetic fields to confine a plasma of fusion fuels, while the other emphasizes the use of high-energy, short-pulse lasers focused on suitable thermonuclear pellets to compress, heat, and ignite the fuel to release the fusion energy. The primary motivation of the laser-fusion program is toward military applications, but the technology has significant potential for application as an electrical energy production system. The laser-fusion program is classified in ERDA-48 as a "Non-Energy Program with Potential Energy Applications."

III H.1

6A.5S SOLAR ELECTRIC ENERGY PROGRAM

The objectives and approach to attainment of the solar electric energy program are provided in ERDA-48, Volume 1[2] and are reproduced in Table III H-1. The details of the program are expanded upon in Volume II of ERDA-48 and a portion of this information is presented in the following material.

1. OBJECTIVES

a. Near-Term (-1985)

To develop technologies and data bases for future implementation of viable ccommercial manufacturing facilities and commercial solar electric generating plants by the mid-1980's, through R&D programs and Federally-sponsored tests and demonstrations of these plants by 1985.

By 1985, the technology provided by the RD&D program, if adopted by industry, will be capable of supporting commercial production of about 10×10^9 KWHe per year, saving about 20 million barrels of petroleum per year. The range of power production capacity contributed by the various types of systems, as normalized to an equivalent load factor of 0.6, would be by 1985:

1.0 to 2.3 GWe from wind energy conversion systems.
0.1 to 0.3 GWe from solar photovoltaic conversion systems.
0.05 to 0.1 GWe from solar thermal conversion systems.
0.05 to 0.1 GWe from ocean thermal conversion systems.

b. Mid-Term (-2000)

By 2000, continued commercial implementation of the technology being developed could supply about 500×10^9 KWHe per year, saving about one billion barrels of petroleum per year. The range of power production capacity contributed by the various types of systems, as normalized to an equivalent load factor of 0.7, would be by 2000:

20 to 35 GWe from wind energy conversion systems.
30 to 60 GWe from solar photovoltaic conversion systems.
20 to 35 GWe from solar thermal conversion systems.
10 to 25 GWe from ocean thermal conversion systems.

Table III H-1

SOLAR ELECTRIC

Objective	Approach to Attainment
To develop and demonstrate technologies for the collection and conversion of solar energy to electric energy to make possible an initial annual energy contribution before 1985 and a moderate contribution (up to 4.5 Quads) by 2000.	. Develop several technologies for commercial assessment: wind systems will be initial contributors; photovoltaic and solar thermal for peak/intermediate electric load applications; and ocean thermal for base load in the long-term. . Sponsor research and development to improve system efficiencies and reduce component costs leading to demonstration projects jointly funded by industry/utilities. . Develop approaches for dealing with institutional, legal and regulatory problems in parallel with technology development. . Conduct by 1985 a comprehensive national solar resource assessment. . Establish in 1976 the Solar Energy Research Institute to assist in the advancement of solar energy use and in transfer of information and technology. . Milestone targets: --1979-1982: 1-10 Mw(e) scale wind systems --1985: Lower cost of photovoltaic elements by 1000-fold --mid-1980's: 100 Mw(e) solar thermal demonstration plant --late 1980's: 25 Mw(e) ocean thermal pilot plant

c. Long-Term (+2000)

By 2020, continued commercial exploitation of solar electric technology developed could potentially supply over 2000 x 10^9 KWHe per year, corresponding to a potential savings of 3.3 billion barrels of oil per year.

2. STRATEGY

Several technologies pursued in this program will have different costs and load matching characteristics. Therefore, several should be pursued until it is clear which are most effective and cost competitive with alternative existing systems. (It should be emphasized that the number and schedule of pilot plants and demonstrations shown in the program are estimated for planning purposes only and are subject to results of R&D projects and availability of budgeted funds in future years.)

Industry, as well as public utilities and other types of users, should be involved in the formative years to accelerate the development and implementation of solar electric energy systems and to assure that economic, technical or other problems affecting the broad application of these technologies are addressed within the program.

The Federal roles will be to undertake and coordinate RD&D to improve performance-to-cost ratios, reduce techno-economic risks and uncertainties, and verify the estimated operational characteristics of solar electric systems so that the public and private sectors can evaluate their economic viability. A program of demonstrations will be undertaken to stimulate public and user acceptance and to provide the basis for eventual large-scale application of solar electric power.

Federal support will also be given to advanced and high risk research associated with solar energy technology development, whose economic benefits cannot be fully captured by individual companies. This involvement will be through federally funded, programmatically related tasks with universities, industrial organizations and other Federal laboratories.

3. SOLAR ELECTRIC SYSTEMS

The program is organized under four sub-programs:

- Wind Energy Conversion Systems (WECS)
- Solar Photovoltaic Conversion
- Solar Thermal Conversion
- Ocean Thermal Conversion

This priority ranking is based on the near-term power production capacity objectives of the four types of solar electric systems and on their present state-of-the-art.

a. Wind Energy Conversion

Problems

Technological:

- The intermittent nature of the wind and the wide geographical and seasonal variations in the availability of this energy source requires either supplementary energy storage capabilities or inter-ties of wind energy conversion systems (WECS) with conventional energy systems. The projected high capital costs of initial large-scale WECS prototypes (i.e. 100KWe, rated, or larger) need to be reduced by a factor of 2 to 4 for such systems to be competitive over very large regions with conventional systems in utility applications. Cost reductions in the area of rotors, hubs, and advanced systems configurations could achieve this goal. Estimates of lifetime of large-scale WECS are uncertain because of insufficient data on operational dynamics of rotors. At present, there are inadequate capabilities to predict realistically the wide characteristics of potential WECS sites and to estimate accurately the power output of WECS units, of a specific design, located at these sites. In addition, there are inadequate system design data available for large-scale systems (particularly large-scale multi-unit systems) and inadequate information on user interface and operational requirements that are needed to accurately optimize and standardize these systems and to determine appropriate and viable applications for them.

Institutional:

- Present institutional problems include: (1) insufficient information on possible environmental effects of large multi-unit WECS

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such as possible radio and television doppler interference caused by rotating WECS blades; (2) insufficient understanding of possible legal and regulatory questions, such as "wind rights"; (3) uncertainties in the public acceptability of large quantities of WECS units on the aesthetics of such units, if they are located, for example, on scenic shorelines and mountain tops; and (4) uncertainties in the availability of sufficient investment capital and experienced personnel to meet the WECS growth rate required to produce a significant impact on the Nation's energy requirements in the near- and mid-terms. In addition, the present acceptability to public utilities of large-scale WECS is limited by their intermittent operational characteristics. These will be acceptable when WECS are used in a "fuel saver" mode; however, their use to supply base load capacity for utility networks will require large associated energy storage capabilities or backup by conventional systems for electrical generation.

Implementation

Applications of WECS will require a wide range of WECS sizes; therefore a parallel implementation approach has been adopted, consisting of the development, test and demonstration of a series of WECS systems of increasing sizes and power output capabilities, supported by a series of R&D projects and studies of institutional constraints.

ERDA and NASA have begun tests on a 100-KWe system, and will complete the preliminary designs of several follow-on 500-KW and MW-scale systems in 1975. 100-KWe and 1 to 2-MWe systems could be operationally tested in specific applications in 1977. Improved systems that incorporate advanced features resulting from the R&D projects could then be developed and operationally tested in the late 1970's. In the early 1980's a series of networks of multiple individual units with total output capacities of 10- and 100-MWe could be incrementally installed and tested.

Methods of improving the performance-to-cost ratios of the types of WECS systems described above will be explored through a series of projects that address rotor dynamics, aerodynamics, construction techniques and system economics.

Advanced system designs, using vertical axis rotors, diffusers and vortex concepts, will be examined.

Projects will be undertaken that examine various possible agricultural applications of WECS including electrolyzing water to produce hydrogen for on-site fertilizer manufacturing, direct heating and crop drying. The capability to rapidly locate and assess sites with sufficiently high average wind velocities for WECS viability will be addressed through modeling, boundary layer flow, wind tunnel tests, and statistical analyses. Separate studies of environmental effects, public acceptance and legal/institutional problems will attempt to quantify these issues and determine their possible impact on the viability of large-scale WECS applications.

Mission and systems studies, at both the national and local levels will provide program coherence and will define regional potential, user requirements and interfaces, standardization factors and cost goals in various applications and climatic zones, with particular emphasis on identifying specific applications not requiring extensive energy storage.

b. Solar Photovoltaic Conversion

Problems

Technological:

- The present technological problems of solar photovoltaic conversion systems, resulting from the seasonal and geographical variations and the diffuse nature of the energy source, require large collection areas for arrays and the availability of either supplementary energy storage capabilities or inter-ties with conventional energy systems. The present costs of materials and processing for photovoltaic arrays are a factor of 50 to 100 too high for such systems to be competitive with conventional systems for widespread applications. In addition, there is a mismatch of the low voltage DC output of photovoltaic collectors to the requirements for many applications. There is also a lack of adequate terrestrial operational performance standards and test data for optimal system design, as well as incomplete identification of possible applications and environmental impacts. Some designs that are being considered exhibit low efficiencies and limited endurance and lifetimes in terrestrial environments.

Institutional:

- Various possible constraints to rapid system implementation include possible ecological impacts of large arrays.

Implementation

Projects are planned through the mid-1980's to improve technical design efficiency, reliability, lifetimes and energy payback times of solar photovoltaic conversion systems through studies on:

- Crystal growth
- Low-cost silicon solar arrays
- Encapsulation
- Alternative materials
- Promising concentrator devices
- Operating and maintenance procedures
- Testing and standards
- Long-term energy storage for independent operations
- Power conditioning and electrical utility grid interfacing

Automatic manufacturing and testing processes and techniques for solar photovoltaic conversion systems will be pursued whose objectives are to achieve a production of solar arrays with a market price of $500/peak KW by 1985 and a solar array production capability of at least 50 GWe peak by 2000, with a market price of $100 to $300 per kilowatt. A demonstration and information dissemination program will be carried out as a Federal responsibility. A series of federally-sponsored tests, demonstrations, and applications of solar photovoltaic conversion systems, with a total installed capacity of at least 100 MWe (peak) could be initiated by 1984. A series of studies will be conducted to determine possible environmental, legal, societal, or institutional impacts, as well as means of removing these types of constraints, if any, on public and user acceptability.

c. Solar Thermal Conversion

Problems

Technological:

- Present technological problems of solar thermal conversion systems resulting from seasonal and geographic variations and the diffuse nature of the energy sources require large collector arrays and either supplementary energy storage capabilities and/or inter-ties with conventional energy systems. There are, also, engineering risks and uncertainties, particularly with central receivers. At present there is a lack of adequate test data and operational performance standards required for optimal system design, as well as incomplete identification of possible environmental impacts.

Institutional:

- Present utilities will be impacted if large numbers of solar thermal systems are integrated into their networks, taxing their capacity during low insolation periods. In addition, selection of early solar thermal facilities must be consistent with long term technical objectives. The use of solar thermal technology must be compatible with state and regional regulation of public utility power networks, and utility interface, maintenance, and operational control of solar thermal total energy systems must be resolved.

Implementation

1976-1979

System, subsystem, materials, environmental and socio-economic studies will be conducted to identify concepts which are economical and address institutional issues.

Parallel contracts will be awarded in 1975 for system concepts, preliminary design, subsystem hardware and testing for the central receiver solar thermal electric power pilot plant. Site selection, design, and construction of a 5-MWt solar thermal central receiver test facility should be completed in 1976-1977 and the facility could be fully operational in mid-1978.

Three additional concepts may be pursued in the late 1970s:

- Design and construction of several 10-MWe pilot plants (e.g., central receiver and distributed collector, with the latter being preceded by a test facility).

- Design and construction of total energy systems for military, institutional, industrial, and residential application to collect data on the technical feasibility and probable operating costs of such applications.
- Preliminary design of hybrid solar thermal systems such as solar thermal-fossil fuel, photovoltaic-solar thermal.

<u>1980-1985</u>

Based on results of research completed in the late 1970s the following concepts may be pursued in the early 1980s:

- Tests which integrate the 10-MWe central receiver pilot plant into a utility grid.
- Continue with the testing of advanced hardware and components at test facilities.
- Construction of a 100-MWe demonstration plant jointly funded by hardware manufacturers and the utility industry.
- Detailed design of distributed collector demonstration plant.

<u>1985 and Beyond</u>

Demonstration plants could be completed and operational experience with these plants utilized in the design of subsequent commercial plants.

d. <u>Ocean Thermal Energy Conversion</u>

<u>Problems</u>

Technological:

- Heat-transfer rates for large volume flows and unusually large heat exchangers and potential associated corrosion need to be identified. Component work will include: ocean engineering problems, low pressure turbine designs, large-scale technology, and unusually large diameter cold water pipes designed for deployment to depths of several thousand feet.

Institutional:

- Environmental impacts associated with circulating large quantities of ocean water need to be determined and weighed. Implications of navigational rules, maritime certification and licensing requirements and resource-recovery structures associated with the Laws-of-the-Sea need to be examined.

Implementation

The proposed development program for ocean thermal conversion systems is comprised of system definition and the development of critical components, followed by prototype and demonstration units.

Facilities should be established on both land and sea for test and evaluation of critical components and subsystems. Supportive studies should be initiated for identifying possible barriers to optimum implementation and to explore energy conversion, storage and delivery systems. Depending on test results and supporting studies, a full-scale floating prototype ocean thermal power plant may be constructed in the 1980's, as results warrant. For the prototype, a full-size platform and pipe would probably be equipped with one power-module of what could eventually be a four module plant. That platform could investigate the feasibility of electricity production and the capability to produce other products, such as fertilizers and fuels such as hydrogen. The following projects may be pursued prior to 1980:

- System design, critical component research and development, and studies of biofouling, materials problems, energy delivery, and legal and environmental issues can be in progress.
- Conceptual and engineering design of a land based test facility would be initiated and conceptual design of a sea based test facility will be completed.
- The land-based facility could be completed by 1979 and tests on initial heat exchanger designs commenced.

Projects in the 1980s may include:

- The design, construction, deployment and testing of a floating 25-Mw prototype ocean thermal energy conversion system, followed by its expansion into a 100-MWe demonstration.

4. OTHER FEDERAL AGENCIES

Research and development in the solar electric energy field is also being conducted in government agencies other than ERDA. A brief description of these complementary efforts follows.

a. National Science Foundation

- Determine characteristics of materials for photovoltaic energy conversion.
- Establish parameters and configurations for evaporators and turbines for open cycle thermal conversion systems.
- Establish feasibility of high-absorption coatings for solar collectors.
- Identify problems of Brayton Cycle as a possible candidate for solar thermal conversion.

b. National Aeronautics and Space Administration

- Manage the project to establish feasibility of low-cost silicon solar arrays.
- Demonstrate economic and reliable wind energy systems.
- Satellite Solar Power Systems Study.

c. Department of Commerce

- Study feasibility of selected alternative materials for low-cost solar cells (for example, cuprous oxide).

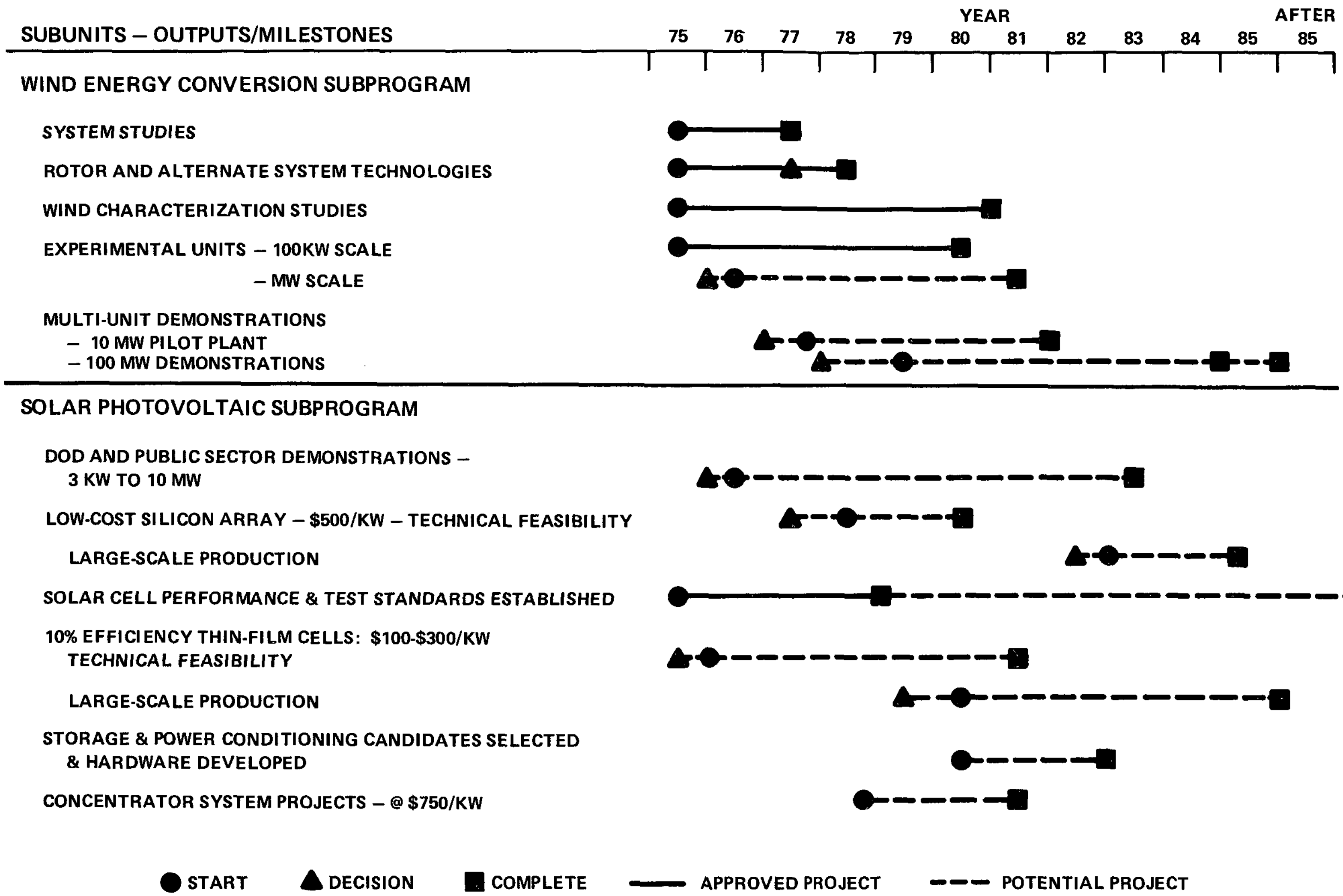
d. Department of Defense

- Advanced Solar Cell Concept Evaluation.
- Purchase of solar cells for isolated stations.

e. Department of Agriculture

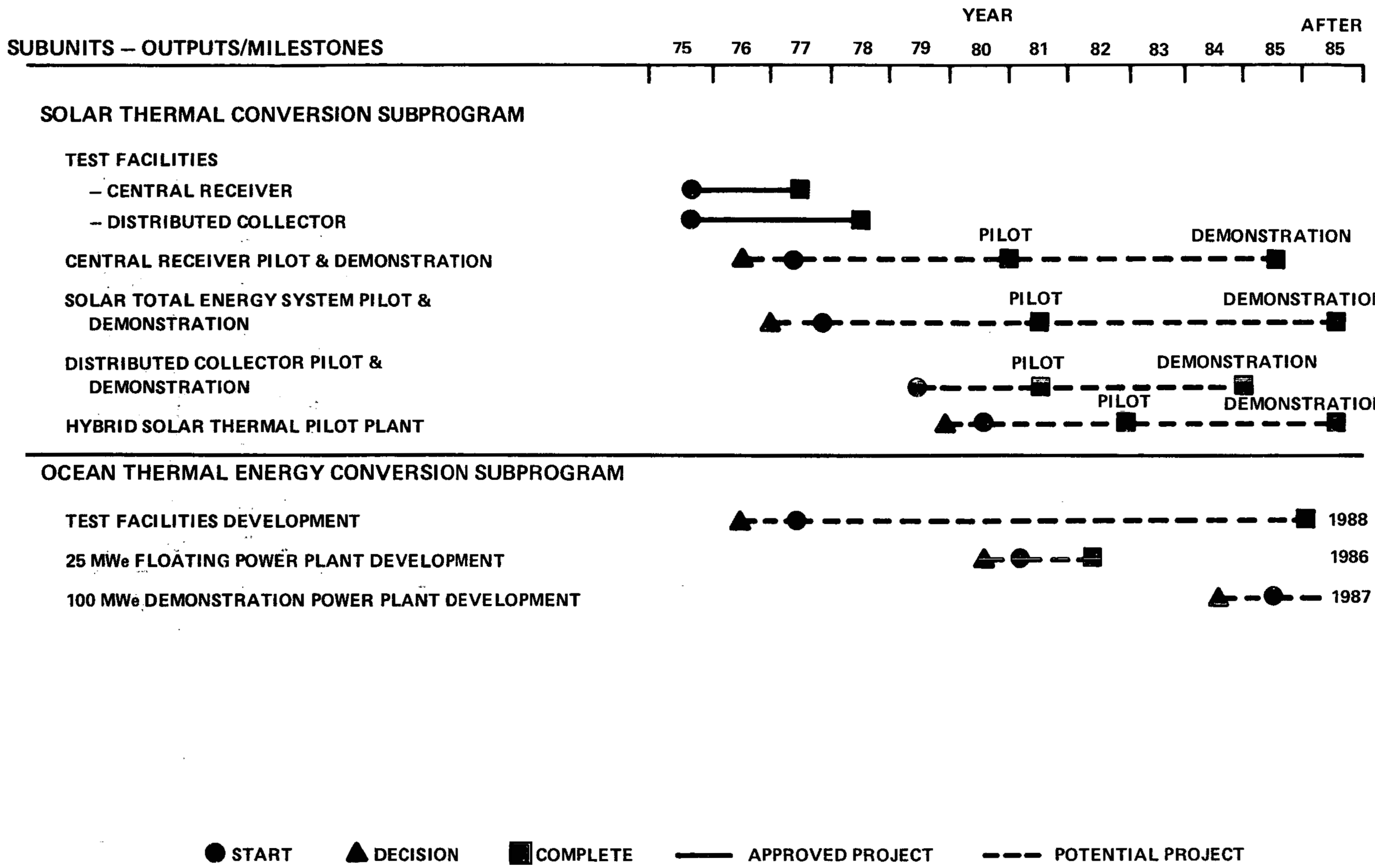
- Demonstrate farm and remote area wind energy applications.

Figure III H-1 provides projected milestones for achievement of the goals of the four solar electric systems being studied.



SOLAR ELECTRIC APPLICATIONS MILESTONES

Figure III H-1



SOLAR ELECTRIC APPLICATION MILESTONES

Figure III H-1 (continued)

6A.1.6S FUSION ENERGY PROGRAMS

1. MAGNETIC CONFINEMENT PROGRAM

The overall objective of the magnetic confinement fusion energy program is defined in ERDA-48:[2]

> "To conduct the necessary research and development to demonstrate the technical, engineering, and commercial feasibility of producing electric power from controlled nuclear fusion to make possible a very major energy contribution in the post-2000 period."

The following table provides the breakdown of the overall fusion energy objective for the magnetic confinement program into three different time frames: near-term, mid-term and long-term.

Table III H-2

FUSION ENERGY PROGRAM OBJECTIVES

Near-Term (-1985):	Produce reactor level hydrogen plasmas. Produce substantial quantities of thermal energy in the First Fusion Test Reactor using Deuterium-Tritium fuel.
Mid-Term (-2000):	Produce electrical energy in substantial quantities in two Experimental Power Reactors between 1985 and 1990. Operate commercial scale Demonstration Power Reactor (1997).
Long-Term (+2000):	Begin supplying a fraction of the Nation's electrical energy demand.

The overall approach to meeting the fusion energy program objectives will be to build and operate a series of progressively larger experimental devices to provide needed knowledge of fusion plasma physics and engineering under prototypical fusion reactor conditions. This will permit an evaluation of the different types of fusion systems and serve as the basis for the design and operation of fusion power reactors. Table III H-3 provides additional details regarding this approach.

A combination of industrial, academic, and National laboratory resources will be used with funding support from the utility industry, where possible, to expand the scope, hasten the pace, and prepare the technology for full commercialization.

There are four major subprograms in the Magnetic Confinement Fusion Energy Program - Confinement Systems, Tokamak Fusion Test Reactor, Development and Technology, and Research. The technological problems and implementation plans for these subprograms are given in Table III H-4. Figure III H-2 provides the projected milestones for achieving each of the four sub-program goals. Additional details regarding these subprograms are presented in ERDA-48, Volume 2, Program Implementation, pp. 84-92.

Table III H-3

APPROACH TO ATTAINMENT OF MAGNETIC CONFINEMENT FUSION ENERGY PROGRAM OBJECTIVES

Provide major Federal support to high risk, high potential payoff fusion R,D&D experiments and tests

Develop both magnetic and inertial confinement approaches

--Use Tokamak concept as most promising magnetic confinement approach
--Develop other alternatives such as: magnetic mirror, theta pinch, laser fusion and electron beam fusion

Encourage near-term industry participation using industrial contractors for new facilities, subsystem supply

Demonstrate reactor level conditions of magnetic confinement from the Princeton Large Torus, Doublet III or Tokamak Fusion Test Reactor facilities now underway and scientific breakeven in inertial confinement using laser or electron-beam facilities under construction or development

Move program orientation from physics to engineering. Design and operate electrical power generating reactors in mid-1980's

Design progressively larger experimental devices leading to jointly funded demonstration reactor prior to 2000

Table III H-4

TECHNOLOGICAL PROBLEMS AND IMPLEMENTATION PLANS - MAGNETIC CONFINEMENT FUSION ENERGY SUBPROGRAMS

Subprogram	Technological Problems	Implementation Plans
Confinement Systems	. Inability of present experimental data and theory to permit full evaluation of fusion power concepts. . Auxiliary heating systems for tokamaks, stabilization techniques for high-density systems, plasma formation techniques for open systems, and superconducting magnets for all three systems are not yet fully developed.	Demonstrate and perfect heating and containment of high temperature plasma while optimizing the plasma configuration to minimize required magnetic fields in tokamak systems. Three large tokamak experiments will be built and operated by 1980. The high-density (theta pinch) and the open system (magnetic mirrors) options will be further developed. This work will be aimed at a possible decision in the 1979-1981 time period on proceeding with a second fusion test reactor based on one of these concepts.
Tokamak Fusion Test Reactor (TFTR)	. Fabricate and operate a fusion energy producing system capable of achieving fusion of deuterium and tritium repeatedly under reactor conditions. Extend the transport and scaling laws of fusion reactor physics. Develop essential components and gain needed fusion reactor experience. . Acceptability of the safety and environmental reports for the project site. . Experimental results, theory, and the development of suitable high-energy neutral beam injectors from other subprograms will provide required support when needed.	The TFTR design is based on existing technology in most areas. Neutral beam injection hardware is being developed (see Development and Technology Subprogram) specifically for TFTR project requirements. Initial operation of TFTR will use hydrogen and deuterium plasmas to gain basic physics data and assure proper operation of all components before proceeding with D-T operation.
Development and Technology	. The near-term technological basis for the engineering of future confinement experiments, fusion test facilities, and fusion power systems must be provided.	Neutral particle injection, resonant radiofrequency heating, and direct energy conversion systems will be investigated.

Table III H-4 - (continued)

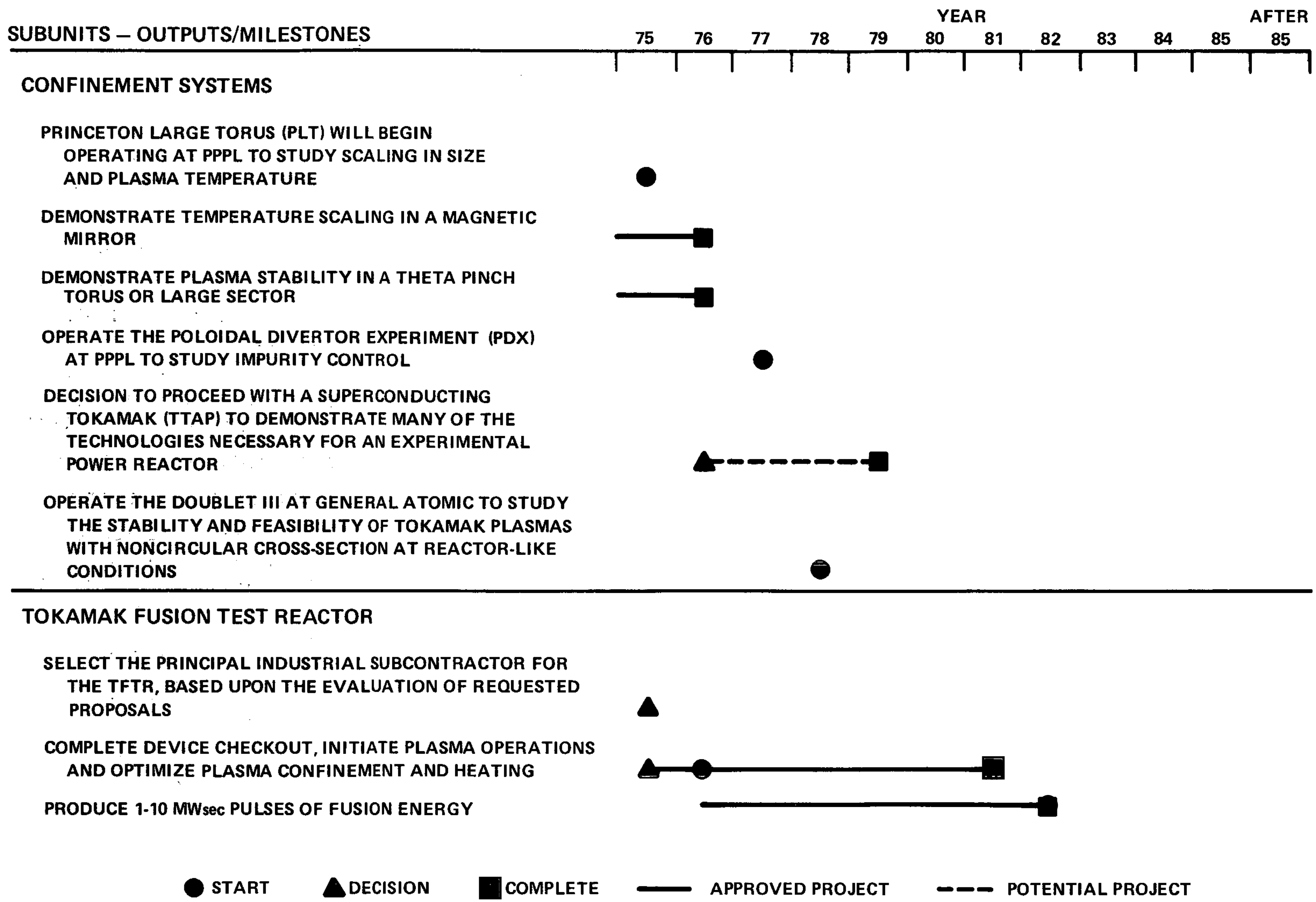
TECHNOLOGICAL PROBLEMS AND IMPLEMENTATION PLANS - MAGNETIC CONFINEMENT FUSION ENERGY SUBPROGRAMS

Subprogram	Technological Problems	Implementation Plans
Development and Technology	. Intermediate-term engineering experience to design, construct, and operate large-scale fusion power reactors will be developed. . Long-term industrial experience and capability for the design and fabrication of reactor components and complete reactor systems has not been fully established.	Development of superconducting magnets, magnet technology, superconducting energy storage coils and systems, superconductors, superconducting switches and homopolar machines will be conducted. Included will be building and testing superconducting magnets for tokamaks and mirrors, inductive and inertial energy storage and switching systems for all major fusion approaches. Six major development areas leading to proof testing and selection of candidate fusion reactor materials are as follows: surface radiation effects; bulk radiation effects; dosimetry, damage analysis, modeling, and simulation; materials selection and development; materials engineering; and neutron source development. This is a major long-lead-time effort critical to the success of the program. Fusion systems studies will coordinate blanket and shield engineering, plasma engineering, tritium recovery and control, and reactor fueling into composite total fusion reactor systems which will successfully demonstrate successive experimental steps leading to technically feasible and economically viable, integrated power reactor systems. Early identification and resolution of both environmental and safety problems for specific fusion facilities will be accomplished as they are conceived, designed and built for the fusion power program as a whole.

Table III H-4 - (continued)

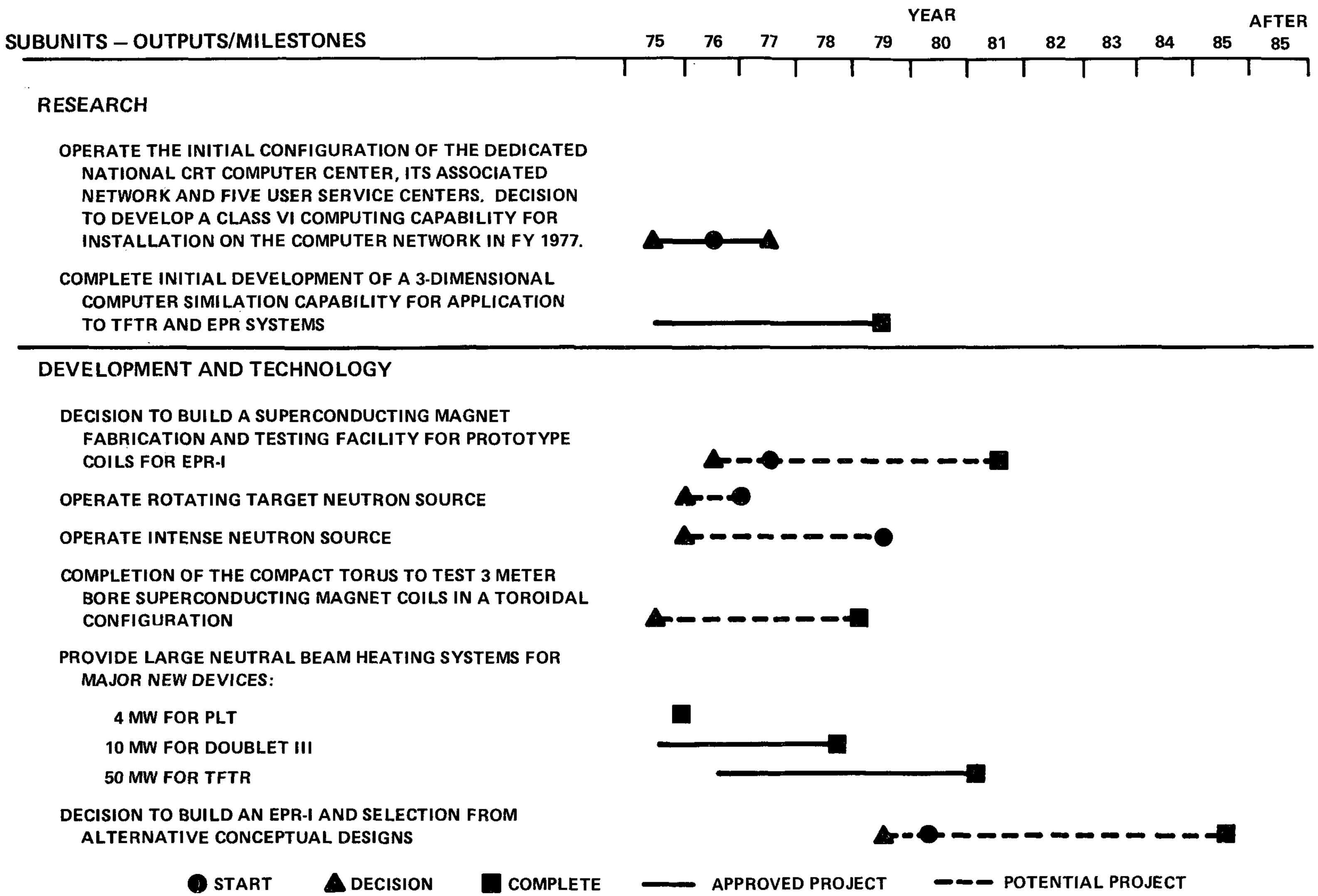
TECHNOLOGICAL PROBLEMS AND IMPLEMENTATION PLANS - MAGNETIC CONFINEMENT FUSION ENERGY SUBPROGRAMS

Subprogram	Technological Problems	Implementation Plans
Research	. A greatly increased analytic and computational capability is required to model the behavior of fusion systems. . New diagnostic techniques and methods of plasma heating and production must be developed to meet the needs of future fusion systems. . Advanced concepts must be explored and tested as possible backup systems and/or possible ultimate improvements over present concepts. . The atomic, molecular, and nuclear cross-sections and properties must be measured to provide better understanding of the properties of the plasma in fusion systems.	Theoretical and experimental research will be conducted to explore new methods of plasma production and heating, to determine atomic, molecular, and nuclear cross-sections specific to the CTR program, to develop and demonstrate new diagnostic techniques, and to study novel fusion concepts. A substantial part of this work will be conducted in universities where it will provide a means of training the new scientists that the growth of the fusion program will require. A CTR Computer Center and associated User Service Centers will be used for Plasma simulations and theoretical calculations and ultimately to predict operating characteristics of fusion power plants. Computational activity on expected plasma properties will be necessary for the design of future reactor experiments. This will require a substantial increase in CTR computing capability because of the complexity of these calculations. Close coordination with the various research communities in Government, industry, and universities will be maintained to ensure cross-transfer of results and to avoid unnecessary duplication of effort.



MAGNETIC CONFINEMENT - FUSION ENERGY SYSTEMS MILESTONES

Figure III H-2



MAGNETIC CONFINEMENT - FUSION ENERGY SYSTEMS MILESTONES

Figure III H-2 (cont'd)

2. LASER FUSION PROGRAM

As mentioned in the Introduction to Section III H, the laser fusion program was initiated with emphasis on its potential military applications. But, in the course of the research and development effort, it became evident that it might have the potential for application as an electrical energy production system. Because the research and development effort is common in many areas for both the military and civilian applications the following discussion, derived from ERDA-48,[2] describes the laser fusion research and development program in general but addresses itself only to the objectives oriented toward civilian applications.

The objectives of the program are the demonstration of the principles of laser fusion and development of military and civilian applications. The civilian applications relate to utilization of laser fusion technology for the development of energy related materials research capability, fuel production and electric power production.

Table III H-5 describes the approach to attainment being used to attain these objectives.

Table III H-5

APPROACH TO ATTAINMENT OF OBJECTIVES - LASER FUSION PROGRAM

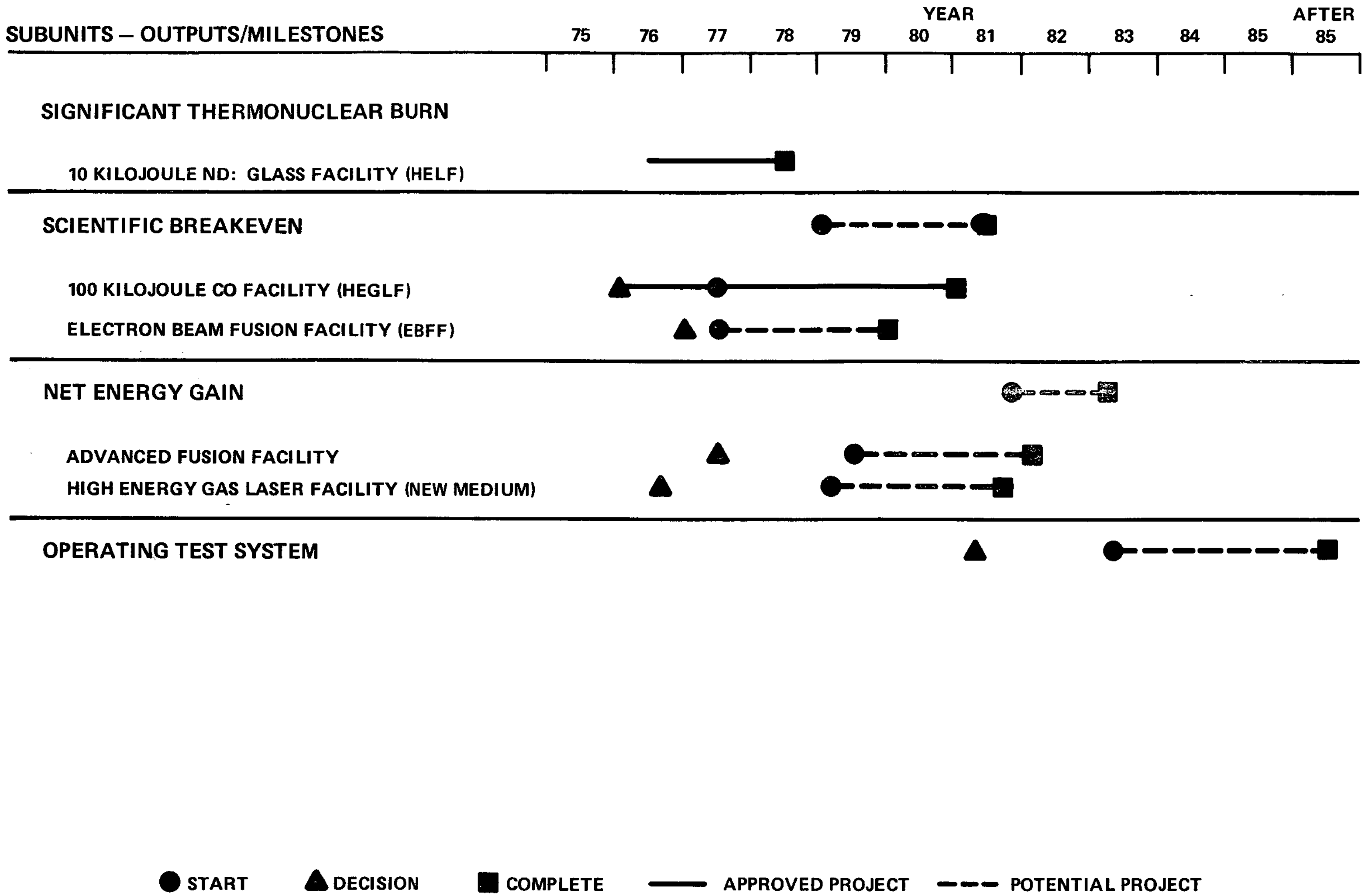
Vigorous research and development and applications core program within the ERDA National Security laboratories.
Make full utilization of unique university and industrial capabilities in support of the core program.
Support broad-based efforts in universities and industry to complement and extend the national laser fusion program base.

The technological problems encountered in the laser fusion program and the implementation plans for resolving the problems and achieving the objectives of the program are provided in Table III H-6. Finally, Figure III H-3 provides the milestones projected for the laser fusion program.

Table III H-6

TECHNOLOGICAL PROBLEMS AND IMPLEMENTATION PLANS - LASER FUSION PROGRAM

Technological Problems	Implementation Plans
. Laser-matter interactions are not completely understood. . Developing consistent theoretical models of physical phenomena. . Developing diagnostic instruments and methodology to measure and confirm the physical phenomena. . Developing the high power, short pulse laser and e-beam systems with sufficient flexibility to deliver the required energy/time profile on target. . Developing applications methodology and devices: - simulation devices - test systems - engineering systems and subsystems	. Demonstration of laser and electron beam induced compressions has been accomplished. . Significant thermonuclear burn (1-10% of D-T fuel in pellet consumed) is the next milestone and is expected to be accomplished in the 1977-1979 period. . An R&D program for the laser system to achieve the scientific break-even and net energy gain milestones continues. . The simplicity, efficiency, and relatively low cost of relativistic electron beam generators make this concept promising for fusion application, and the Electron Beam Fusion Facility to be completed in 1979 will provide the capability to prove the basic concepts of e-beam fusion. . Supporting R&D continues to acquire diagnostics, materials, and control technology for the program. . An operational test system is postulated by the mid-1980's and a demonstration plant for the mid-1990's. . Additional military applications will be developed as identified and defined from the basic research program.



LASER FUSION ENERGY SYSTEM MILESTONES

Figure III H-3

REFERENCES FOR SECTION III H

1. Administrator's Findings (June 30, 1975) on the Liquid Metal Fast Breeder Reactor Program Proposed Final Environmental Statement, WASH-1535 (December 1974).

2. A National Plan for Energy Reserach, Development and Demonstration: Creating Energy Choices for the Future (ERDA-48), Volume 1: The Plan, and Volume 2: Program Implementation, June 28, 1975.

3. Letter, Robert C. Seamans, Jr., to the President of the United States, The President of the Senate and The Speaker of the House of Representatives, June 28, 1975.

<u>SECTION IV</u>

<u>MATERIAL RELATING</u>
<u>TO PFES REVIEW</u>

INTRODUCTION

This section contains the Administrator's Findings on the Liquid Metal Fast Breeder Reactor (LMFBR) Program Proposed Final Environmental Statement (PFES), WASH-1535, and additional material used by the Administrator in reaching these Findings.

Section IV A is the Findings on the LMFBR Program PFES issued by Dr. Seamans, the Administrator, on June 30, 1975.

Section IV B is the June 20, 1975 Report of the Internal Review Board to the Administrator on the LMFBR Program PFES. The Internal Review Board consisted of four senior ERDA officials not previously involved in the Statement's preparation, and was commissioned by the Administrator to undertake an objective and comprehensive review of the PFES. The members of the Board were Mr. Robert W. Fri, Deputy Administrator, Dr. John M. Teem, Assistant Administrator for Solar, Geothermal and Advanced Energy Systems, Dr. James S. Kane, Deputy Assistant Administrator for Conservation, and Dr. S. William Gouse, Deputy Assistant Administrator for Fossil Energy.

Section IV C contains reviews of the PFES by 4 knowledgeable scientific and technical individuals outside of ERDA. These reviews were requested by Dr. Seamans to assist him in his review of the PFES. These reviews were performed by Mr. Walter H. Zinn, a consultant and former Combustion Engineering, Inc. executive, Dr. Alvin M. Weinberg of the Institute for Energy Analysis and former Director of the Oak Ridge National Laboratory, Mr. Donald B. Rice, President of the Rand Corporation, and Dr. Cyril L. Comar, Director of the Environmental Assessment Department, Electric Power Research Institute.

SECTION IV A

ADMINISTRATOR'S FINDINGS ON THE LIQUID METAL FAST BREEDER REACTOR PROGRAM PROPOSED FINAL ENVIRONMENTAL STATEMENT

UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
WASHINGTON, D.C. 20545

ADMINISTRATOR'S FINDINGS ON THE
LIQUID METAL FAST BREEDER REACTOR PROGRAM
PROPOSED FINAL ENVIRONMENTAL STATEMENT

1. In reaching the findings set forth herein, I have reviewed the following materials:

(a) The Proposed Final Environmental Statement (PFES) on the Liquid Metal Fast Breeder Reactor (LMFBR) Program issued by the former Atomic Energy Commission (AEC) in December 1974;

(b) Comments thereon received from government agencies and members of the public;

(c) The record of a public hearing on the PFES conducted May 27-28, 1975, by a Review Board composed of the Deputy Administrator, the Assistant Administrator for Solar, Geothermal, and Advanced Energy Systems; the Deputy Assistant Administrator for Fossil Energy; and the Deputy Assistant Administrator for Conservation (none of whom had previously been involved in the preparation or review of the PFES);

(d) The report of the Review Board;

(e) The written views of several knowledgeable scientific and technical individuals outside the Energy Research and Development Administration (ERDA).

In addition, I have considered the PFES in relation to the comprehensive plan for energy research, development and demonstration, covering solutions to short-term, middle-term and long-term energy supply systems and associated environmental problems, which ERDA is submitting to the Congress on June 30, 1975, in fulfillment of Section 6 of the Federal Nonnuclear Energy Research and Development Act of 1974, P.L. 93-577, enacted December 31, 1974.

2. The PFES was prepared by the AEC to comply with the decision of the U.S. Court of Appeals, District of Columbia Circuit, in Scientists' Institute for Public Information, Inc., v. Atomic Energy Commission et al., 481 F.2d 1079 (June 12, 1973). This decision established that Federal agencies must conduct comprehensive environmental reviews of major technology development programs, and consider, at an appropriate time prior to any irreversible commitment, the projected impacts of eventual commercial deployment of the technology being developed. The Court considered that it was then timely and feasible and hence required by the National Environmental Policy Act of 1969 (NEPA) to issue a statement on the environmental impact of the LMFBR Program as a whole, including ramifications of commercial deployment and alternative courses of action.

3. In accordance with guidelines of the Council on Environmental Quality (CEQ), the PFES was first issued in a draft form for public comment. After consideration of extensive public and agency comments submitted in writing and at a public hearing, it was subsequently prepared in final form. However, the AEC issued it in December 1974 as a Proposed Final Environmental Statement, in view of the forthcoming establishment of ERDA

on January 19, 1975, and the realization that future decisions on such a significant long-term developmental matter were properly for ERDA to make. Issuance in this form permitted ERDA, in accordance with the AEC's recommendation, and with the concurrence of CEQ, to provide another round of public comment and another public hearing on the Statement and the LMFBR Program.

4. ERDA inherited the developmental responsibilities of the AEC, but not its regulatory powers. These were assigned to a new agency, the Nuclear Regulatory Commission (NRC), which is independent of ERDA in every way. ERDA's determinations to pursue developmental programs are, of course, not binding on NRC, and under section 202 of the Energy Reorganization Act, LMFBR's for commercial demonstration are subject to licensing by the NRC.

5. In addition to the AEC's developmental role in nuclear energy, ERDA was given strong statutory mandates to conduct research, development and demonstration programs in nonnuclear energy sources. See, e.g., the Federal Nonnuclear Energy Research and Development Act of 1974, the Solar Energy Research, Development, and Demonstration Act of 1974, and the Geothermal Energy Research, Development and Demonstration Act of 1974. Construing all these nuclear and nonnuclear statutory mandates in harmony with each other, we believe that the role of ERDA is to generate an array of safe, sound, environmentally compatible energy technology options for selection and use by the country as a whole. ERDA is not to dictate which choices are to be made, but rather to assure that choices <u>can</u> be made.

Of course, ERDA must establish priorities among possible courses of action, and ERDA must accord special weight to the environmental consequences of its developmental decisions. ERDA is also charged with preparing, reporting, and adhering to a comprehensive energy research, development, and demonstration plan with particular attention to the environmental problems associated with alternative solutions to energy supply system needs. This plan, the first edition of which is being sent to the Congress on June 30, 1975, is to be revised annually and submitted to Congress concurrently with the submission of the President's budget.

6. It is from this perspective, which naturally differs from that of the AEC, that ERDA has reviewed the PFES on the LMFBR Program. On the basis of this review of the record, the comments by agencies and members of the public, the views of the experts outside of ERDA, and the Report of the ERDA Review Board (which I hereby adopt), and from the insights I have gained in preparing the comprehensive plan, I make the following findings.

7. The PFES amply demonstrates the need to continue research, development and demonstration of the LMFBR concept. There is no presently available or prudent alternative to this course of action. This technology holds the promise of an essentially inexhaustible source of energy to satisfy a significant share of this Nation's energy needs in the next century. While LMFBR technology is not the only technology which may be able to satisfy this objective, significant uncertainties concerning timely availability of the other major candidates, which are solar electric and fusion energy, make it risky and imprudent to discard the LMFBR Program

on the basis of what we presently know. It is simply too soon to confirm with sufficient reliability that these alternate technologies will be available on time and in adequate quantity. It is speculative at this time that these options would be environmentally preferable to the LMFBR technology. Moreover, while I do not adopt any particular growth projection, including those postulated in the PFES, I cannot now discount the possibility that contributions from all three technologies will be desirable or needed to meet future energy demands. The possible needs are such, and the promise of energy from inexhaustible sources so great, that all three technologies must be pursued on a priority basis.

8. In the light of these considerations, only a demonstration that the LMFBR can <u>not</u> be developed as a safe, environmentally sound and economically competitive energy source would justify a decision to discontinue the program. The record before us does not so indicate. I adopt the conclusion of the PFES and the Review Board that the significant problems identified in the LMFBR concept may be solved by a continuation of the Program.

9. At the same time, these significant problems, as identified by the Board, including in particular those related to reactor safety, safeguards, health effects, and waste management, remain unresolved at this time. They must be resolved satisfactorily before any decision may be made to place LMFBR's into widespread commercial use. I concur with the Board that research, development and demonstration are needed to resolve these matters and that the PFES as it stands is not and cannot be a conclusive

or satisfactory assessment of the environmental impact of a fully commercialized breeder reactor industry. Continuation of the research, development and demonstration program does not prejudge any decision concerning the commercialization of this technology. I concur with the Board that while these two questions are related, they can be separated from each other. I find that continuation of the LMFBR Program at this time would not lead inexorably or irresistably to a full "breeder economy," if further work were to demonstrate that the problems of the breeder cannot be resolved. Specifically, I do not find that completion of the Clinch River Breeder Reactor (CRBR) project,* an integral part of the Program, is tantamount to widespread commercialization. As a practical matter, NRC would almost surely refuse to license breeder reactors if there were an ERDA finding that major problems were unresolvable. At the same time, as indicated above, NRC (unlike the former AEC) would be in no way bound by an ERDA environmental impact statement or an ERDA recommendation that the technology was ready for commercial use. Nor do I find that continuation of the program at this time would inevitably short-change the other technologies we must develop. Indeed, these other programs are receiving substantially increased new appropriations and are proceeding as rapidly as possible consistent with prudent management and efficient use of public monies.

10. It will be necessary over the next few months to carefully reexamine the current developmental program to be sure that it is most

* It is noted that the CRBR is subject to a separate site-specific environmental impact statement, which will be issued in connection with the application for licensing of the demonstration plant.

efficiently structured to solve the problems that need solution. A major weakness of the PFES is that aside from termination no alternatives are presented to continuing the program precisely as set forth in the PFES. As Administrator, I need to consider alternative methods of conducting the program to be sure that -

(a) the research, development and demonstration activities are properly directed to resolve the remaining technical, environmental, and economic issues in a definitive and timely way;

(b) these issues are resolved before a final decision concerning the acceptability of commercial deployment is made; and

(c) test and demonstration facilities that are needed in the LMFBR Program are conservatively designed to protect the health and safety of the public and to provide useful information for subsequent environmental, economic, and technical assessments.

11. The PFES will be supplemented or amended, as appropriate, to reflect these conclusions and provide the information called for above. The resulting document, which will constitute ERDA's Final Environmental Statement and complete the NEPA process on this action, will be issued within approximately three months. Meantime, the Program will be carried forward at the rate and level of authorization reflected in Congressional action on the budgetary proposals ERDA has recently submitted. Because the CRBR Project has been substantially delayed, this decision entails no environmentally irreversible action during this period and for substantially more than thirty days after the Final Statement is issued.

12. ERDA will maintain continuing scrutiny on the LMFBR research, development and demonstration program as it develops. ERDA clearly has the responsibility to make a determination whether commercial deployment of the LMFBR concept is warranted, although it is also true that no commercialization is possible without favorable licensing action by NRC. Accordingly, as the program develops and significant new information pertinent to the commercial deployment issue is generated, ERDA will update the existing Environmental Statement or prepare a Supplement to it, or even a new Statement, as may be appropriate and consistent with the National Environmental Policy Act. On the basis of this updated record, together with the periodic revision of the LMFBR Program, and the annual updating of the Comprehensive Energy Research and Development Plan, ERDA will subsequently evaluate the environmental acceptability and economic feasibility of widespread commercial use of LMFBR's. To be meaningful, this consideration will take place before any commitment to widespread commercial use becomes irreversible. At the same time, ERDA will pursue, as vigorously as result-oriented management will permit, programs for long-term energy technologies that can be evaluated by this agency, the Congress, and the marketplace as alternatives or supplements to breeder reactors.

13. In concluding, I observe that the PFES is a faithful, and in many ways, remarkable performance. Perhaps it is, as some commentators have asserted, more strongly "promotional" than a severely-stated scientific recital would be. I can accept that criticism without agreeing that it disqualifies the document as a useful (if not exclusive) foundation for

ERDA's decisional process. In discounting the promotional tone, I note that ERDA does not have a partiality towards any single form of energy. We feel it to be totally consistent to carry on the LMFBR Program and, at the same time, to carry on the fullest kind of research and development into nonnuclear technologies, at a pace limited only by the need to build up the new programs efficiently and effectively.

14. Finally, I want to acknowledge the thousands of hours many devoted people have spent in preparing, reviewing, and criticizing this voluminous document. It is indeed an impressive accomplishment, on the part of both those who support this development program and those who oppose it, particularly the possible commercialization application. It is my belief that the intensity of the review process has assured, and will continue to assure, that difficult choices are soundly made.

Robert C. Seamans, Jr.

Robert C. Seamans, Jr.
Administrator

June 30, 1975

SECTION IV B

REPORT TO THE ADMINISTRATOR

ON

THE PROPOSED FINAL ENVIRONMENTAL IMPACT STATEMENT

FOR

THE LIQUID METAL FAST BREEDER REACTOR PROGRAM

BY

THE INTERNAL REVIEW BOARD

June 20, 1975

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Report to the Administrator

By memorandum, dated April 9, 1975, the Administrator of ERDA commissioned this Internal Review Board to undertake an objective and comprehensive review of the Proposed Final Environmental Impact Statement (PFES) on the Liquid Metal Fast Breeder Reactor (LMFBR) Program which has been prepared pursuant to the National Environmental Policy Act (NEPA). The Board has evaluated the PFES in light of the wealth of written views submitted in response to a solicitation of comments in the Federal Register (40 F.R. 3804) and the record of an informal public hearing conducted by the Board on May 27-28, 1975. We have also drawn upon the special expertise which the Board members bring to bear with regard to alternative energy production and conservation technologies in formulating the findings and conclusions which are set forth in this Report.

I. Scope and Method of Review

In accordance with the charter of the Board, this Report: identifies the issues which are relevant to the Administrator's decision, particularly as disclosed by the comments; sets forth the Board's findings on the adequacy of the treatment of these issues in the PFES; considers whether the options contained in the PFES have been adequately evaluated and whether all relevant options have been considered in the PFES; and, where deficiencies are identified, suggests measures for ensuring that the record before the Administrator is rendered adequate for decisionmaking.

Notably, the Board was not requested to resolve the outstanding issues or to formulate recommendations on the course of the LMFBR Program itself. The essential function of the Board has been to assure that the Administrator's decision is soundly based rather than to interject its own judgments into the decisional process. It is the view of the Board that a sufficient record for decisionmaking is one which is conducive to a deliberate consideration of the environmental and economic factors of the LMFBR Program on its own merits and within the larger context of the range of actions reasonably available to achieve the objectives of that Program.

In light of its mission, the scope of the Board's examination is reducible to two inquiries:

1. Whether the discussion of issues in the PFES provides a sufficient basis for determining the acceptability of the environmental and economic aspects of the LMFBR Program;
2. Whether the discussion of alternatives in the PFES provides a sufficient basis upon which a reasoned choice may be made among available courses of action.

In evaluating the sufficiency of the PFES, the Board has adopted an analytical approach which recognizes that ERDA's consideration of the environmental significance of this developing technology may entail a sequence of incremental decisions concerning the course, timing and relative priority of the Program. A single, discrete decisional point on the question of environmental acceptability is rendered impractical by the evolving nature of the technical, environmental and economic data which bear crucially upon ERDA's posture toward this Program. Accordingly, this Report endeavors to specify the types of decisions for which the PFES, in present or revised form, is considered to be sufficient and those for which it is not.

Particularly, two types of decisions are distinguished. Since the impacts of widespread use of LMFBR's flow logically, if not inevitably, if ERDA successfully completes its research, development and demonstration (RD&D) task, we recognize that ERDA has a responsibility to consider the environmental consequences of not only the development of the technology but also its deployment.[1/] Thus, a crucial component of ERDA's environmental review and decisionmaking is to determine whether pursuing breeder technology to the point where it becomes available for commercialization is inadvisable. This entails consideration of whether the resulting environmental impacts will be unacceptable and whether alternative energy resources, more attractive from an environmental standpoint, are sufficiently certain to be realized to fill the gap left by an undeveloped LMFBR technology. ERDA's consideration of this matter, to be meaningful, must

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1/ This approach is consistent with the view reflected in the U.S. Court of Appeals' opinion in Scientists' Institute for Public Information v. AEC, (481 F.2d 1075 (D.C. Cir. 1973)) which mandated the environmental review of the LMFBR Program under NEPA; in the PFES (Preface, pp. 1-5 and Summary, p. 1.1-2); and in many of the comments which have been considered by the Board (most notably, those of the Environmental Protection Agency, see Comment Letter 84, p. 2; and Hearing Record, Tab 16, item 3).

take place before the "technology attains the stage of complete commercial feasibility," to borrow a phrase from the judicial opinion which mandated the environmental review of the LMFBR Program. Of course, if ERDA carries the research, development and demonstration (RD&D) effort to completion, the decision on commercialization will be made by regulatory agencies, which will also consider the environmental acceptability, and ultimately by the marketplace, largely on the basis of economic rather than environmental factors.

In the judgment of the Board, it is both appropriate and convenient to detach the decision on the course of the LMFBR Program from the decision on the environmental acceptability of the mature technology 1/ for the purpose of judging the sufficiency of the PFES.

The criteria which the Board applied in evaluating the PFES reflects this analytical approach. With regard to the discussion of issues, the Board has reviewed the comments in order to determine whether the essential issues have been explicated in the PFES, and whether the information on these issues provides a reasonably firm ground upon which the environmental

1/ The Board observes that the consideration of the environmental acceptability of the LMFBR technology in light of the full range of acceptable courses of action cannot be deferred entirely to the private sector or the Nuclear Regulatory Commission. Since these entities approach the matter from a different perspective, with different considerations and a different range of choices, their determinations are not the functional equivalent of ERDA's distinct role.

and economic benefits of both the development and the deployment of the technology can be weighed against the environmental and economic costs and risks. The Board evaluated the issues only to the extent that their treatment in the PFES was called into question by the commenters. In determining whether the discussion of the controversial issues is sufficient for decision making, the Board examined the following features of the PFES:

1. The degree of factual accuracy;
2. The degree of completeness, including the presentation of important adverse viewpoints;
3. Its objectivity, particularly concerning the range of uncertainty attending critical parameters, analyses or conclusions; and
4. The extent to which more reliable, complete or useful information may be developed in the course of this or other programs.

The Board has assessed the discussion of alternatives in light of the objectives to which the LMFBR Program is apparently directed. The distinction which we have drawn for decisionmaking purposes between the developmental program and the deployment of the technology corresponds with the dual objectives of the LMFBR Program as we discern them from the PFES. At one level, the purpose of the Program is to provide a solid technological basis by which it can be determined whether a safe, economically competitive and environmentally acceptable technology can be developed. The second and ultimate purpose of the Program is to make available to the utility industry an acceptable technology option for the large-scale commercial production of electrical energy.

The dual objectives of the LMFBR Program, in turn, define two types of alternatives which warrant consideration. Alternative methods of developing the technology are comprised of a range of program plans involving variations on timing, facilities, research, testing, decision points and similar components. Alternative methods of achieving a comparable level of commercial production of electricity consist of various "mixes" or strategies of resource utilization, alternative technology development and conservation schemes which could substitute in whole or in part for the energy which would be provided by widespread use of LMFBR's. For convenience, the first level of alternatives will be referred to as "programmatic alternatives" the latter as "technological alternatives."

The sufficiency of the discussion of alternatives at each level is judged by the exent to which it provides a basis for determining:

1. Whether the alternatives are, or will be, reasonably available within the period during which the benefits of the LMFBR Program should accrue;
2. If so, whether any such alternatives would be more or less attractive than the base program from the standpoint of environmental quality or net economic benefit; and
3. What significant uncertainties exist with respect to these determinations, and when and how they may be resolved.

Applying the foregoing criteria to the matters within the scope of this review, the Board finds that the PFES is comprehensive in identifying the key issues for the Administrator's decision; that the discussion of issues critical to a decision on the course of the RD&D Program is reasonably satisfactory, with exceptions which are specifically noted; that the treatment of the information currently available concerning the issues and technological alternatives necessary for an informed decision on commercialization is reasonably complete and accurate, but is necessarily of limited value for determining whether alternatives to an LMFBR economy will be available and whether they will be more or less protective of environmental quality; and that these unresolved matters are amenable to solution, partially or completely, by further RD&D efforts.

Clearly, the most fundamental weakness of this otherwise prodigious document is its failure to set forth and assess options within the Program. The PFES presents the LMFBR Program as though it must be accepted or rejected as a whole, thereby depriving the Administrator of the opportunity to choose the optimal structure and pace from among the full range of available courses.

II. Issues Concerning the Environmental Impacts and Economics of the LMFBR Program

The major and recurrent issues raised by commenters involve the safety of LMFBR's, the safeguarding of special nuclear materials and facilities from incursions, the management of high-level radioactive wastes, the health effects attributable to routine and accidental or intentional releases of radioactive materials, and the analysis of economic costs and benefits of the LMFBR Program. These subjects have received detailed if not exhaustive treatment in the PFES. The challenges of the commenters are mounted with regard to rather specific omissions and infirmities in the discussion which is presented.

A. Reactor Safety:

The Board discerns three predominant issues concerning the PFES treatment of reactor safety: (1) while the PFES concludes that hypothetical core disruptive accidents (HCDA) will be found to be physically unrealizable and that the upper bound consequences can be economically contained, critics argue that a significant degree of uncertainty attends these matters and renders the expectations of the PFES premature; (2) the PFES and its critics agree that substantial data and analysis must be developed on the design and performance of LMFBR components and integrated systems before the risks of the LMFBR can be evaluated quantitatively, but the significance of the lack of risk quantification data for present decisionmaking is subject to disagreement; and (3) given the uncertainties in the current state of knowledge, there is a divergence of opinion as to whether LMFBR's can be designed and operated with adequate margins of safety.

The assertion of the PFES that HCDA's either will not occur or can be economically contained is called into question by comments of the

Nuclear Regulatory Commission [1/] which are echoed by the Natural Resources Defense Council (NRDC).[2/] For example, NRC observes that (1) assertions that solutions can be found to potential design problems are not definitively supported in the PFES; (2) the conclusion that the consequences of HCDA's could be contained within the primary coolant boundary of the reactor is premature since this matter is currently under study; (3) the characterization of HCDA energetics may be understated; (4) further research is needed to evaluate the effective mechanical damage from power bursts; (5) statements in the PFES concerning fuel-coolant interactions are presumptive since it is not apparent that all potential interaction mechanisms have been identified; and (6) NRC contraverts the PFES position that recent assessments have diminished the estimates of HCDA consequences. The common theme running through the NRC commentary is that significant uncertainties remain to be resolved within the LMFBR Program before the safety of LMFBR's can be finally determined.

We note that the PFES contains scant information concerning the research necessary to resolve the outstanding safety problems.[3/] However, much additional information on this subject was submitted into the hearing record by the ERDA staff.[4/] It indicates that the primary effort of the

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1/ Comment Letter 56, pages 4-7.

2/ Comment Letter 55, pages 5-24; and hearing transcript, page 279.

3/ PFES Section 4.2.7 and Annex A, p. 4.2-165.

4/ Hearing Record Tab 15, items referring to pages 29-35 of the hearing transcript.

ongoing safety research is to establish that no exceptions lie undetected with respect to the present conclusion that the preconditions of HCDA's releasing significant energy cannot be met in LMFBR's. Results of the planned research are expected between 1978 and 1980. The staff document concludes that completion of the research will likely permit conservative designs to give way to more functional and flexible approaches which will improve the economics of the reactor.

The staff has also supplemented the hearing record with information concerning the development of risk quantification methodologies for LMFBR's. 1/ Sources of the uncertainty which remain to be resolved within the Program include: the limited amount of operating data on components; the lack of data from large-scale plants; and the lack of detailed understanding of in-core phenomena. The research will entail adapting the "branching-ratio" methodology of the Rasmussen analyses to LMFBR's. Development of this methodology will permit components and systems to be ranked with respect to their relative contribution to overall plant risk. In turn, this will establish priorities for further research and development of components and systems and provide risk assessment procedures which can be utilized by mid-1985 for safety evaluations and licensing.

NRDC and other critics of the LMFBR technology argue that the PFES is a defective basis for a decision on the LMFBR Program in the absence of definitive information on the energetics of HCDA's and a

1/ Hearing Record, Tab 15, items referring to pages 29-35 of the hearing transcript.

quantified risk analysis. On the other hand, the PFES with amplification in the hearing record, 1/ indicates that uncertainties in these areas can be accommodated by conservative design of demonstration or commercial reactors. The PFES exemplifies this approach by adopting conservative assumptions, in the absence of quantified data, in its presentation of risks from reactor accidents. Thus, Table II G-2 2/ lists the contribution to the transuranic releases from tabulated types of LMFBR accidents assuming ten-year intervals between accidents for each such reactor. In this instance, the conservative assumption as to frequency of occurrences is found to be inconsequential since the total estimated contribution from accidents is so trivial that it is adequately accounted for within the figures derived for the routine releases.

The Board's evaluation of the record indicates that specific information on the direction and timing of research into these reactor safety matters is a significant omission in the PFES and that the research needs detailed in the staff's submissions into the hearing record more accurately reflect the current state of technology than any suggestion in the PFES that uncertainties have already been dispelled. Aside from these difficulties, the PFES presents the currently available data in as much detail as can be reasonably expected. Particularly, we were

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1/ Hearing Record, Tab 5, item 1, page 8; Tab 15, items referring to pages 29, 34 and 35 of the Hearing Transcript; and Hearing Transcript, pages 28-33.

2/ PFES, page II.G-7.

impressed with the fact that answers to the outstanding questions are to be found, if at all, by continuation of the RD&D efforts, at least for the near-term.

B. Safeguards:

The treatment of this subject in the PFES has been assailed on a broad front. Commenters, primarily NRDC,[1/] allege the following deficiencies: (1) the PFES fails to clearly articulate a standard of performance to which the safeguards program will be designed, hence it cannot be determined whether the level of residual risk will be acceptable; and (2) the PFES fails to provide sufficient detail on the safeguards program to permit a judgment as to whether the objectives can be achieved. In sum, it is alleged that the PFES fails to support its conclusion that the residual risk will be acceptably low.

According to the PFES, [2/] the standard of performance which the safeguards program will be designed to attain is a level of protection to the public which would not increase significantly the overall risk of death, injury, or property damage from causes beyond the control of the individual. NRDC finds the stated objective uninformative in that it fails to indicate unequivocally whether essentially zero risk of involuntary casualty from an LMFBR economy is achievable or, if not,

1/ Comment Letter 55, pages 48-60; see also, the hearing testimony of Dr. Barry Smernoff, Hudson Institute, transcript, pages 80-98; Comment Letter 48, Dr. John T. Edsall, Harvard University.

2/ Page 7.4-3.

whether some greater quantum of risk is deemed acceptable. Staff testimony at the hearing 1/ indicates that a zero risk safeguards system is not considered feasible, but that the goal of the program is to reduce the risk to the "absolute minimum" achievable.

In view of the ambiguity, NRDC proposes that the level of risk deemed acceptable and achievable be made explicit in terms of the quantity of deaths and injuries and the amount of property damage which would be considered tolerable. This information is not presented in the PFES. While the PFES recognizes that the consequences of a successful diversion of special nuclear materials could be extremely grave, 2/ it does not attempt to quantify the risk on the rationale that the frequency of such occurrence cannot now be estimated.

More precise definition of the safeguards risks and goals is certainly relevant to the acceptability of an LMFBR economy. Moreover, the Board believes that further research into the safeguards concepts and technologies described in the PFES 3/ is a prerequisite to the postulation of standards of performance. Social choices should be made on the basis of a reasonably precise quantification of the risks to be incurred rather than upon a necessarily imprecise projection of the degree of protection deemed attainable in advance. We recognize, of course, the statement of objectives

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1/ Hearing Transcript, page 315.

2/ PFES, pages 7.4-15 to 25.

3/ Pages 7.4-30 to 64.

or standards of performance in the PFES is also rather meaningless until the results of this research become available.

As in the area of reactor safety, the PFES asserts that ongoing studies will confirm the conclusion that the safeguards objectives will be met in a timely manner. 1/ An abundance of additional information on the safeguards research and development program has been submitted into the hearing record by the ERDA staff. 2/ This information, indicating the direction and timing of the efforts to resolve safeguards uncertainties, is generally not presented within the PFES.

The supplemental materials disclose a number of strategies for upgrading and evaluating safeguards measures. Development of portal monitors is underway to reduce to gram quantities the amount of materials which could pass undetected outside of controlled areas. A material accountability system is under development to provide rapid and accurate measurements of material balances for much smaller segments of plant operations than was previously possible. This type of control, it is claimed, requires a potential diverter to steal materials in sufficiently small quantities so that each removal would be masked by measurement uncertainties. To obtain significant quantities, a large number of thefts must be committed with a concomitant high risk of detection.

1/ Page 7.4-92.

2/ Hearing Record, Tab 15, items referring to page 27, 41, 319 and 324 of the hearing transcript; and staff testimony, page 36 to 46 of hearing transcript.

Efforts addressed to improving the design and evaluation of safeguards systems involve the analysis of event-trees and adversary action sequences. It is the Board's impression that this effort has not progressed beyond the problem definition phase. Apparently, the nature, magnitude, and frequency of the problems and their potential solutions are largely unresolved at this time.

The consequences of successful sabotage of LMFBR facilities or transportation elements are deemed to be no greater than those associated with accident scenarios assessed in the PFES. 1/ However, it is noted that additional research is required to confirm this conclusion. 2/ Again, the degree of risk is not quantified due to the unknown frequency of occurrences.

Other concepts of potential advantage in containing safeguards-related risks, called "minimization activities" are listed in the PFES. 3/ Little useful discussion is provided concerning the degree to which implementation of these measures would reduce the risk of successful adversary action against LMFBR facilities.

The testimony of Dr. Manson Benedict in the transcript of the public hearing 4/ is informative on one of the mitigation measures: the concept

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1/ PFES, pages 7.4-24 and 25.

2/ PFES, page 1.4-12.

3/ PFES, pages 7.4-60 and 7.4-80 to 87.

4/ Pages 161 to 166.

of locating fuel reprocessing plants and fuel fabrication plants at the same site. Since undiluted plutonium is only available at these stages of the fuel cycle, Dr. Benedict is of the opinion that the risk of diversion during transportation between such facilities could be minimized by such "colocation." The PFES discusses at some length the economic advantages of this option but largely neglects to assess its significance as a safeguarding measure. All "minimization activities" which would render vulnerable materials unavailable or unsuitable for diversion need to be fully explicated before the level of residual risk can be ascertained.

Central to the concern over this issue is the perception that the PFES fails to confront the residual risk inherent in any safeguards system which, by its very nature, can never attain absolute perfection. According to this view, even assuming the success of the ongoing research and development effort, and assuming the implementation of minimization concepts, the safeguards system will remain basically a human institution subject to inherently human failings. It is not apparent that a technological approach to the safeguards problem can entirely obviate errors in judgment or venality on the part of the nonmechanistic, human component of the safeguards problem. As the number of facilities and period of operation expands, a serious deviation from idealized procedures becomes progressively more likely to occur. These observations lead some commenters to conclude that some residual risk is inevitable and that the hazard associated with special nuclear materials renders this risk intolerable.

Due to the human component again, this view also holds that meaningful risk quantification will remain beyond the state of the predictive art. Therefore, it will never be possible to determine the true extent of the risk, or judge its acceptability, except from the historical vantage point.

While the gravity of these concerns is not to be dismissed lightly, absolute certainty of predictive models is not, in the Board's judgment, an attainable standard. However, we believe that additional information on safeguards from the ongoing studies may improve the basis on which the magnitude of the residual risk can be evaluated and on which a decision as to the acceptability of the risk may be made.

C. Waste Management:

The PFES concludes that high-level radioactive wastes from LMFBR fuel reprocessing plants can be successfully managed by retrievable storage facilities for the near term and by disposal in geological formations for the remainder of their hazardous lives. 1/ The discussion admits that a permanent solution to the problem is not at hand, but concludes that a timely solution will be developed.

NRDC 2/ takes the position that the magnitude of the risk from high-level waste is such that the environmental review of this technology should not be terminated until a proven and acceptable permanent disposal mode is available.

1/ PFES, Section 4.6.

2/ Comment Letter 73.

The Board is cognizant that a critical re-examination of waste storage strategies is currently underway in this agency. Accordingly, it is not realistic to freight the PFES with a definitive examination of the problem. The PFES contains the relevant but inconclusive information to the extent that it has been developed. The conclusion that a timely permanent disposal solution will be found may be premature but further research and development on waste management strategies must precede a final determination on the environmental significance of this aspect of the LMFBR fuel cycle.

D. Health Effects:

Much of the controversy concerning projected health effects from the LMFBR fuel cycle has been evaluated in the previous discussion of this Report. The unresolved issues involving reactor safety, safeguards inadequacies and waste management to a large extent translate into concerns that the potential releases of radioactive materials have been understated in the PFES leading to a consequent underestimation of the health effects attributable to the technology.

Remaining for examination is the contention that the cancer incidence from plutonium in the lung may be several orders of magnitude greater than calculated by the PFES for a given level of exposure. This result follows from the hypothesis that tumor induction from plutonium in particulate form is far greater than from an identical dose uniformly distributed in the lung. The supposition is known as the "hot particle" hypothesis and, once again, the chief exponent is the Natural Resources Defense Council. 1/

The outstanding issue is whether the hot particle hypothesis should be assumed as an additional degree of conservatism in projecting health effects from inhaled plutonium.

The discussion in the PFES sets forth and evaluates at some length the logical and experimental basis put forth for the hypothesis. 2/ It is rejected as a predictive model primarily on the grounds that "an abundance of experimental animal data indicates that particles are less hazardous in the lung than a uniformly distributed dose of the same activity," and because of the lack of observed health effects in workers who have inhaled hot particles.

NRDC, in the latest round of comment on this subject, contends that the hypothesis, properly understood, is not disconfirmed by experimental or observational data; that the PFES is defective for failure to respond to NRDC's refutation of the AEC analysis of the problem; and that the PFES, in rejecting the hypothesis, relies upon expert opinion which is not objective on the question.

1/ Comment Letter 55, pages 42-48, and supplemental enclosures entitled "NRDC Supplemental Submission to the Environmental Protection Agency Public Hearings on Plutonium and the Transuranium Elements," and "The Hot Particle Issue: A Critique of WASH-1320."

2/ PFES, Appendix II. G.6.

In the judgment of the Board, this dispute turns upon peculiarly recondite matters of health physics and cannot be resolved within the confines of an environmental impact statement. It must await the verdict of the scientific community. The conclusions of the PFES appear to be based upon the considerable weight of current informed opinion and are therefore as adequate for decisionmaking as the state of the art will allow.

E. Cost-Benefit Analysis:

A quantification of the intrinsic merits and demerits of the LMFBR Program is found largely within the Cost-Benefit Analysis of the PFES.[1/] However, it should be recognized that this analysis is far more exhaustive in its presentation of benefits than of costs. The costs accounted for in quantitative terms are exclusively economic in nature. The less tangible environmental and health costs and risks are discussed elsewhere in the PFES (and we have examined this discussion above), but they are not factored into the computation of monetary costs attributable to the LMFBR technology.

In the judgment of the Board, this is not an impermissible approach. Indeed, it is difficult to imagine how such risks could be reduced to dollar figures or otherwise quantified in a meaningful way. The analysis is simply not amenable to precise valuation. Nevertheless, an inherent limitation in the usefulness of the Cost-Benefit Section results.

1/ PFES, Section 11.

Even where dollar costs are involved, they are not uniformly factored into the analysis. For instance, costs due to reactor accidents and diversion of plutonium may result from implementation of the technology. Additionally, the present state of knowledge does not discount entirely the possibility that costs may accrue to future generations from a failure to contain huge inventories of radioactive wastes. But, since the frequency, and to some extent the magnitude, of these events cannot be presently computed, no meaningful dollar figures can be derived.

It is also the view of the Board, however, that these unquantified impacts should not be overlooked in the decisional process. The record should be sufficient to indicate that they exist and, to the extent possible, the significance which should be attached to these unknowns. The foregoing portions of the Report examine the sufficiency of the PFES in these regards and indicate the areas in which additional information needs to be developed. We turn now to an evaluation of the treatment of the quantified benefits and costs.

The internalized (economic) costs attributed to development and operation of the LMFBR industry include all projected utility and governmental investments and operating expenses except funding for general support activities generic to other nuclear or nonnuclear plant concepts, such as environmental and safeguards studies. 1/ The projected program costs associated with introduction of the LMFBR in 1987 are estimated in

1/ PFES, page 11.2-39.

the Analysis to be $8.4 billion (discounted to $4.7 billion at 10% discount rate to 1974).[1/] The Board notes that projected program costs have now escalated somewhat above that figure.

The monetary benefit considered is the projected reduction in total energy costs over the planning horizon from 1970 to 2020 obtained by introducing the LMFBR. [2/] The benefit is primarily due to the lower fuel cost obtained by reduction in the requirements for uranium ore and separative work capacity.

Three assumptions underlying the Analysis appear to be critical to the results:[3/]

1. Electric energy demand projections for the reference (base) case assume an annual rate of growth in demand of 7.8% in 1970 declining continuously to 3.7% in the year 2020. Sensitivity analyses are also conducted for demand projections 20% and 50% below the reference case.
2. The uranium resource estimate is set at four million tons excluding shale.
3. The capital cost differential between LMFBR and LWR powerplants is assumed to be $100 per kWe initially, declining to a zero differential by 2000 due to a presumed manufacturing learning curve.

1/ PFES, page 11.2-32.

2/ PFES, page 11.2-2.

3/ PFES, pages 11.2-5 to 15.

The introduction date for LMFBR power plants is assumed to be 1987 with sensitivity analysis run for 1985 and 1991.[1/] The results computed at 10% discount rate (with program costs associated with a 1987 introduction date of $8.4 billion discounted to $4.7 billion) show substantial net benefits accruing for most cases. The notable exceptions are cases in which two of the critical parameters are allowed to vary in an unfavorable direction simultaneously.[2/]

Several commenters challenged the values of the critical base parameters, most arguing that they are unduly skewed in favor of the benefit side of the balance. Natural Resources Defense Council,[3/] in their submittal "Bypassing the Breeder," takes the position that a more realistic view of the future would find all three critical parameters moving in directions unfavorable to the LMFBR. This NRDC projection, combined with optimistic assumptions concerning the contribution to energy supplies from nonconventional sources, shows that for every $10 spent on developing the breeder, the public will recoup only $1 in lower energy costs on a discounted basis.

By contrast, Dr. Thomas Stauffer, a Harvard University economist who has studied breeder economics for private industry, testified at the public hearing that the anticipated benefits of the LMFBR will be

1/ PFES, pages 11.2-16, 11.2-119 to 134.

2/ PFES, pages 11.2-15 to 31.

3/ Comment Letter 55.

generally higher than the values given in the PFES.[1/] Restricting his analysis to the "economic logic" of the development program, as distinct from a commercialized industry, Dr. Stauffer reports discounted benefits of $70-$100 billion, accepting the PFES base assumptions for uranium supply and postulating a 5.1% compound rate of growth in energy demand through 2020. Dr. Stauffer finds the breeder economics to be quite sensitive to introduction dates but relatively insensitive to capital cost projections for the breeder. It may be significant that Dr. Stauffer employs a 6% discount rate in his calculations which he believes to be proper in an analysis of a technology which is competing with others for the same research funds.

The issue concerning realistic energy growth projections reduces to a choice of indicators. Environmental organizations including NRDC,[2/] Scientists' Institute for Public Information,[3/] the Environmental Protection Agency[4/] and others point to very recent projections which indicate a rate of growth lower than the 50% below base case presented in the PFES. The recent decline in population growth, price elasticity, conservation measures and changing life styles are put forward as grounds for the lower projections.

1/ Hearing Transcript, pages 394-419.

2/ Comment Letter 55, supplemental enclosure entitled "Bypassing the Breeder," Appendix, pages 21-30.

3/ Comment Letter 66, pages 4-6, III-1 through IV-8.

4/ Comment Letter 84, pages 3, 9-20.

Dr. Barry Smernoff[1/] of the Hudson Institute has testified that growth patterns are now passing through an inflection point toward equilibrium. He admits, however, that stabilization of the electrical demand curve may lag behind the trend due to substitution of electrical energy for other energy sources.

Dr. John T. Edsall[2/] of Harvard University, in his written comments, illustrates the great potential for energy conservation with data from the Ford Foundation Report, "A Time to Choose: America's Energy Future."

The industry and ERDA staff views on the matter are that the recent downturn in demand is a minor perturbation in an otherwise stable demand curve which correlates positively with gross national product.[3/] Moreover, even if growth in energy consumption in general declines, oil and gas reserves will become depleted in the short-term necessitating greater reliance upon fission technologies. Thus, Commonwealth Edison and Dr. Stauffer expect a 6% annual load growth with substantial basis to support a 7% to 8% growth projection.

1/ Hearing Transcript, pages 80-111.

2/ Comment Letter 48

3/ Hearing Transcript, Tab 5, item 1, page 17; Tab 6; Tab 16, item 8; Hearing Transcript, pages 57-58, 65-66, 114, 125, 180-185, 233-235, 449-451.

A similar divergence of opinion has been expressed concerning the PFES base estimates of economical and undiscovered uranium resources. Critics of the Cost-Benefit Analysis find the base projections to be unrealistic and rely instead upon the "optimistic" cases in the sensitivity analyses.1/ Commonwealth Edison and other industry participants at the public hearing, by contrast, argue that the ERDA estimated resources are now largely committed to fuel existing reactors necessitating the use of lower grade ores, with the attendant large scale land disruptions, for plants constructed after the mid-1980's.2/

The controversy concerning the PFES projections for LMFBR capital costs revolves around the attribution of a 2% per unit reduction in the capital cost differential between LWR's and LMFBR's for each doubling of LMFBR capacity placed into operation. NRDC challenges this assumption on the ground that a similar learning curve has not occurred in the LWR industry and should not therefore be anticipated with respect to LMFBR's.1/ The ERDA staff respond that the LWR's learning curve has simply been eclipsed by increased environmental and safety design expenditures. The industry is now deemed sufficiently mature so that the latent learning reductions will soon become discernible. LMFBR's, by contrast, will benefit from the environmental and safety design work which has accumulated

1/ See, e.g., Natural Resources Defense Council, Comment Letter 55, "Bypassing the Breeder."

2/ Hearing Transcript, pages 118 and 196.

in the LWR industry so that their entry onto the learning curve will be expedited.[1/]

The Board is wary of facile attempts to resolve these areas of controversy, dependent as they are upon future events which are now more or less speculative. With regard to projections of energy demand, it seems prudent to assume a moderate level of growth for planning purposes. This is so not because ERDA is committed to any particular growth scenario, but simply because the penalties for underestimation are likely to be far more severe than those for overestimation. A program can be scrapped if its need does not become actualized. But the long lead times involved in research and development programs and plant construction make it relatively difficult to accelerate efforts which have been held in abeyance pending an unmistakable confirmation of their need.

With respect to uranium resources, the Board is impressed with the view of Dr. Stauffer that there is no reliable methodology by which extrapolations can be made from known reserves.[2/] Although significant information can and no doubt will be developed in advance of physical exploration, optimism beyond that reflected in the cost-benefit projections may be unwarranted at this time.

1/ PFES, pages 11.2-78 to 86.

2/ Hearing Transcript, pages 399-401.

Due to the vagaries of the manufacturing and construction industries, it seems equally perilous to speculate at this time on the capital cost question. We note that the PFES brackets these areas of uncertainty with sensitivity analyses indicating the influence of various assumptions upon the results. Future events will narrow the bands of uncertainty and permit a more reliable verdict on the LMFBR economics.

In the interim, the Board finds that the PFES is reasonably complete and sufficient for present decisionmaking.

The assumptions employed as to energy demand, uranium supply and capital costs may eventually prove to be unrealistic and therefore reduce the calculated benefits. On the other hand, it would be risky to underestimate the advantages of the R D & D Program at this time. Indeed, the value of better information seems undisputed, and, as it becomes available, the record should be supplemented and the course of the Program reevaluated.

The Board believes that while the final verdict on the economic costs and benefits of a commercial LMFBR industry must be left to the utility industry, ERDA must reserve to itself the judgment as to whether the noninternalized environmental costs, balanced against the net economic benefits of a prospective LMFBR industry warrant a continuation of the Program to the point of commercialization. The present record is not deemed to be ripe for this determination.

F. <u>Conclusions on the Sufficiency of the PFES Treatment of Issues</u>:

At the outset, the Report listed the two inquiries which are involved in the task to which the Board has been assigned. The first of these is whether the discussion of issues in the PFES provides a sufficient basis for determining the acceptability of the environmental and economic aspects of the LMFBR Program.

The Board's conclusions with respect to this inquiry are framed in terms of the two distinguishable types of decisions which ERDA is called upon to make with regard to the Program: those pertaining to the acceptability of the developmental program and those pertaining to the acceptability of a mature commercial industry.

The PFES is a reasonably complete source of information on the issues of reactor safety, safeguards, waste management, plutonium toxicity and the economics of the breeder, given the significant areas of uncertainty which remain to be resolved. Exceptions to this conclusion have been noted in the foregoing sections. We have observed that the record could be improved by including in ERDA's final impact statement on this subject the information in the hearing record pertaining to the direction and timing of the reactor safety and safeguards research programs. Additionally, sufficient information on the strategies for mitigating safeguards risks should be supplied to indicate the effect of such measures upon the level of residual risk.

With these exceptions, the Board finds that the PFES discussion of these issues is sufficient to support a determination as to whether the environmental consequences of continued research, development and demonstration are acceptable in view of the potential benefits from the technology and the value of resolving significant areas of uncertainty. As the following sections will indicate, additional information is needed for a decision as to the actual structure and timing of the continuing Program.

The significant environmental impacts of research and development (without reference to the broader ramifications of commercial deployment) would appear to include (1) those associated with the construction and operation of demonstration facilities, and (2) potential environmental benefits foregone in the event that funding of the LMFBR Program precludes or delays the development of more environmentally attractive alternative strategies. The PFES is acceptable as a record of the impacts which would attend the construction and operation of developmental and demonstration facilities. Some useful discussion of the relative environmental benefits and impacts of the alternative technologies is provided in the PFES. This discussion is further evaluated in Section III of this Report.

The effect of continued LMFBR R D & D upon alternative technology development programs is dependent in part upon future fiscal policies, both within and beyond the control of ERDA. With the supplementation which we have recommended, we believe the PFES will be suitable to lend guidance to the allocation of ERDA's future budgetary priorities. To the extent that the future funding constraints which may come to bear upon technology development programs depend upon political contingencies which cannot be anticipated, these are not proper subjects for inquiry within an environmental impact statement in the Board's view.

With regard to the acceptability of widespread deployment of commercial LMFBR's, however, the information in the PFES is not deemed sufficiently complete or reliable for a final judgment. Significant uncertainties have been identified in this Report concerning the environmental impacts and economics of an LMFBR economy which remain to be resolved by the ongoing R D & D Programs, particularly in the areas of safeguards and waste management, and by the investigation of the quantity of recoverable uranium resources.

III. Discussion of Alternative Energy Sources and Technologies

The technological alternatives to the LMFBR technology are comprised of the reasonably available strategies of technology development, resource utilization and conservation schemes which could, individually or in concert, supply benefits comparable to a commercial LMFBR industry.

We find the PFES discussion[1/] of alternatives to be a reasonably complete and accurate compendium of the individual energy production and conservation sources, both currently available and under development. However, while the PFES is unswervingly optimistic concerning the resolution of technical difficulties with regard to the LMFBR, its view of the development of other technologies is often unduly pessimistic. This tendency detracts somewhat from the value of the PFES as a wholly objective and dispassionate portrayal of emerging technologies.

1/ PFES, Section 6.

The most extreme illustrations are found in the descriptions of solar and geothermal technologies. The assertion in Section 6.A.5.8. of the PFES, that the only solar application of potential significance is as thermal energy for buildings, seriously underestimates the prospective role of this energy source. Solar electric technologies as well as bioconversion and solar thermal energy for industrial and agricultural applications are promising and potentially abundant sources of usable energy. The PFES apparently ignores these applications in concluding that "solar energy will not materially reduce the need for alternative electric energy sources in this century."[1/]

Similarly, the contribution of geothermal energy is presently estimated by ERDA to substantially exceed the rather insignificant role projected for this source in Section 6.A.4.2.2. of the PFES. The description of other technologies, including fusion, however, is generally comparable with present concepts and projections as set forth in ERDA's comprehensive energy research, development and demonstration plan, entitled "Creating Choices for the Future."

We do not find that the discrepancies in the PFES projections render that document inadequate for decisionmaking. The position of the PFES that there are no prudent alternatives to continuing the LMFBR Program at this time is amply supported. This conclusion is predicated upon the rapid depletion of oil, gas and fission fuels,

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1/ PFES, page 6A.5-30.

the lack of assurance that nonconventional energy sources will be viable and economic contributors in the near future, and the apparent assumption that the future energy demand of this country will be of such magnitude that all energy sources which can be developed will be needed.[1/]

While the first two predicates are adequately supported by the PFES, the latter assumption depends, of course, upon future energy consumption trends which are understood only imperfectly at this time. The Board agrees with the conclusion that all promising energy technologies should be pursued for the near term, but for the reason that we cannot now know which will prove successful, economic, and environmentally acceptable.

In one sense, the LMFBR Program has no rival simply because it is so much nearer to fruition that it enjoys a higher probability of success than alternative technologies. Thus, while the PFES demonstrates that there are no prudent alternatives to the LMFBR Program presently available, it may turn out that more attractive options will ultimately be developed to substitute for widespread commercial usage of the LMFBR technology. It is apparent that considerable R D & D of the alternative technologies identified in the PFES must take place before it can be known whether viable and attractive substitutes to the large-scale deployment of LMFBR's will be available. This decision, like those concerning the environmental acceptability of an LMFBR economy, must be deferred until this critical information becomes known.

1/ See, e.g., Hearing Record, Tab 5, item 1, page 14.

We note two respects in which the present record should be supplemented when this critical information becomes available. First, the PFES does not, in a comprehensive or rigorous manner, assemble individual alternatives into "mixes" or strategies calculated to provide a choice between reasonably available courses of action.[1/] For the most part, alternatives are assessed discretely without indication of whether certain combinations might substitute in whole or in part for an LMFBR economy. The Board is aware of the uncertainties which plague such an analysis, but in its absence, it is difficult for a decisionmaker to ascertain the extent or significance of the uncertainties, or the range of choices actually or potentially available.

Secondly, a quantified and detailed cost-benefit analysis, of the type accorded the LMFBR technology, is not conducted with respect to the other sources of energy which are identified in the PFES. Some general discussion of this nature is provided in Chapter 11, but there is no attempt to predict in a comparably detailed manner the relative cost-effectiveness or net economic benefit which might be derived from these energy systems. Consequently, a completely satisfactory basis for comparison with the LMFBR Program is not provided.

1/ Although Section 11.2 gives cursory attention to one conventional and one nonconventional mix, the PFES does not present a definitive analysis by which it can be determined whether other mixes are worthy of consideration or whether any such strategies may be more environmentally attractive than the LMFBR technology.

On the other hand, information for conducting such analyses is not uniformly available. The Board observes that, particularly in the case of those potential sources which may compete with the LMFBR as essentially inexhaustible energy sources (e.g., solar electrification and fusion reactors), cost-benefit projections are decidedly premature.

For the purposes of determining the present course of the LMFBR Program and allocating funding priorities among the developmental programs, we therefore find that the PFES discussion of alternatives is as sufficient as present knowledge will permit. Presumably, as the emerging technologies mature, relatively reliable information concerning their economics and environmental significance will be developed. This information is deemed to be critical to future decisions concerning the allocation of developmental priorities among the various technologies, including the breeder reactor, and to the eventual decisions concerning their commercial deployment.

IV. Discussion of Programmatic Alternatives

The program plan presented in the PFES envisions expeditious completion of the research, development and demonstration program and subsequent deployment of the technology at the discretion of the utility industry.

Section 3 of the PFES describes the LMFBR Program plan. Other sections of the document provide some information on associated research programs. However, those discussions concentrate on the objectives of the programs and the physical constituents of particular facilities.

Less information is provided on the sequence of steps, the timing, the problem definition, the methodology, or the appropriate points at which further decisionmaking would occur. In general, variations on the pace and structure of the effort are not presented or evaluated in the PFES. Consequently, the range of courses available to achieve the development of an economically competitive and environmentally acceptable technology is not disclosed.

The absence of programmatic alternatives in the PFES is disturbing. As previously indicated, we find the PFES adequate for determining whether the LMFBR Program should be continued. It sufficiently demonstrates that no reasonably available alternatives presently exist to the continuation of the Program due to the uncertainties attending the availability of competing technologies. It is therefore deemed adequate for determining whether the LMFBR Program should be maintained at an effective level for the near-term. We have also indicated that additional information, to be gleaned from this and associated research and development programs, is needed before the environmental record can be closed on the question of commercialization. Thus, we believe the PFES justifies continuation of the LMFBR Program at some level beyond merely sustaining the research and development effort, but short of a present commitment to commercialize the technology. While the Administrator may wish to choose a course between these extremes, the absence of programmatic alternatives in the PFES hampers this choice. In short, we find that the PFES is sufficient for a decision on whether, but not how, to continue the LMFBR Program.

We are mindful that continuation of the Program in order to resolve the outstanding uncertainties, could, in some forms, entail a commitment to deployment of the technology, despite the uncertainties. This may occur if the Program progresses to the stage where a private-sector decision to implement the technology could preempt ERDA's further consideration of the matter in light of the new information being developed. We observe that as the Program proceeds, it may become more difficult to curtail due to the momentum which it builds and the investment which it absorbs. There is a sense in which this process tends to prejudice further choices as the imminence of the technology begins to predominate over environmental considerations as a judgmental element.

Therefore, in structuring the course of the Program, we believe the Administrator should have before him reasonably complete information on the range of options available for achieving the technology development objective, and on the manner in which these options relate to the ultimate decision concerning deployment. The decisions on the course of the Program must depend, in part, upon the existence of programmatic options which reserve for later judgment the question of whether commercial deployment of the technology is environmentally acceptable. We find the PFES uninformative on the manner in which the program plan relates to the private-sector decision on commercialization. Hence, it cannot be determined on the basis of that document whether, at what points, and by what means that decision can be controlled until ERDA's verdict on the matter can be rendered.

Moreover, the appropriate decision points for this reconsideration are not disclosed. Presumably, they are a function of the availability of research results from this Program, the associated safeguards, waste management and uranium resource projects, and the ongoing efforts to develop alternative technologies. The PFES fails to indicate the manner in which these collateral studies key into the LMFBR Program plan. It is therefore difficult to ascertain when or whether significant new data will become available for consideration. This information is essential in order to build into the structure of the LMFBR Program meaningful and timely decision points. Without it, the choice of an optimum course for the LMFBR Program becomes a matter of conjecture rather than of deliberate appraisal.

V. Recommendations Concerning the Form and Content of the Final Environmental Impact Statement

An essential component of the Internal Review Board's charter, discussed in Section I of this Report, is to make suggestions for ensuring that the record before the Administrator is adequate for decisionmaking. The Board has concluded that, while the PFES is generally suitable for a decision on the course of the LMFBR Program, certain deficiencies do exist. We have indicated that additional information which is presently available should be sufficient to cure the defects in the present record. Recognizing the obligation of ERDA to develop a final impact statement on this Program for use as a tool within the decisional process, we recommend that this supplemental information be incorporated into that document.

To summarize our earlier conclusions, the following specific information (some of which is available within the hearing record) should be set forth in the final statement:

1. The final statement should discuss the sequence of steps, the timing, the problem definition and the methodology of the various ongoing studies and programs which are relevant to the environmental and economic acceptability of an LMFBR industry. These studies include the LMFBR safety program and related inquiries concerning safeguards, waste management, and uranium resource availability;
2. It should set forth the optimal points in the LMFBR Program plan at which major issues identified in this Report can be expected to be resolved;
3. It should indicate the optional courses of action available to the Administrator in structuring the LMFBR Program, so that a present decision can be made on that Program, while at the same time reserving for later judgment the question of whether implementation of the technology is acceptable.

4. In addition to detailed information concerning the safeguards research and development program the final statement should describe the minimization concepts listed in the PFES and assess the extent to which each of these can reduce the safeguards risk;
5. Finally, the final statement should indicate the points at which reliable information on alternative technologies for the production and conservation of energy will become available for further consideration.

Another feature of the PFES may make it unsuitable, standing alone, to serve as ERDA's final statement on this matter. The PFES contains policy judgments as to the acceptability of environmental risks and conclusions as to the desirability of the program plan as described therein. These conclusions should be considered as proposed findings tendered by the staff, rather than as the articulation of ERDA policy. To the extent that the Administrator does not wish to adopt these findings as his own, the PFES should be conditioned by appropriate disclaimers in the final statement.

In light of these considerations, we recommend that a final statement be prepared incorporating the PFES by reference with an indication of the extent to which the Administrator adopts or rejects its analyses and conclusions; and the additional information which this Report has identified should be developed and included in the final environmental impact statement.

In short, the final record should be an ERDA document, responsive to the additional environmental review which has been accorded and reflecting the broad and balanced approach to energy research and development which is ERDA's novel mission.

VI. Conclusion

This Report indicates that the PFES is sufficient for some decisions but not for others.

The Board concludes that the PFES, in its present form, is a sufficient factual record for determining whether the LMFBR Program should be continued. It demonstrates that the potential value of the technology as an energy source and the present value of resolving outstanding technical and environmental problems weigh heavily in favor of pursuing the Program in some form, at some pace and at some level of priority. We believe that the PFES substantially supports its conclusion that there are no clearly available and prudent alternatives to a continuation of the Program at the present time.

The PFES fails to provide a sufficient basis for a choice among possible Program courses which would structure the Program in an optimum fashion in light of the objectives, funding constraints, technological uncertainties and other considerations which enter into this agency's planning function. The type of information deemed important to these decisions is indicated throughout this Report. It is the Board's impression that this information is currently available and can be assembled into the record for a present decision on the Program course.

Finally, the PFES is not sufficiently complete or accurate with respect to several matters bearing upon the environmental acceptability of deployment of the technology. On the other hand, the record strongly suggests that the unresolved environmental problems and the uncertainties concerning technological alternatives are amenable to solution, wholly or partially, in the course of the ongoing research and development programs.

In discharging its responsibility to conduct an objective evaluation of this environmental record, the Board recognizes that it brings to the task a degree of institutional predilection in favor of the development of energy technologies. It has sought to temper this perspective by attending closely to the significance of outstanding uncertainties in the present state of the record in relation to the several types of decisions which can be distinguished concerning this Program. It is on this basis that we conclude that decisions on whether the LMFBR technology should be made available for deployment, thereby incurring the ramifications of a large-scale commercialized industry, be made only after a more complete record is provided through additional research, development and demonstration of this important energy option.

Submitted June 20, 1975.

Robert W. Fri
Chairman of the Internal
Review Board

SECTION IV C

REVIEWS OF SEVERAL KNOWLEDGEABLE SCIENTIFIC AND TECHNICAL INDIVIDUALS OUTSIDE THE ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION (ERDA)

May 25, 1975

Dr. Robert C. Seamans, Jr.
Administrator
Energy Research & Development Administration
Washington, D. C. 20545

Dear Dr. Seamans:

In response to your and Mr. Fri's request, I have read a large part of the Proposed Final Environmental Statement for the LMFBR program. As you well realize, the Statement is a massive document which contains an enormous amount of technical detail and to this is added the extensive remarks, also containing technical details, which have been communicated by both proponents and critics of the LMFBR program.

From my review, I conclude that any questions I had or which occured to me while reading the document almost certainly are answered, at least to some degree, somewhere in the many pages of direct presentation or in the AEC responses to comments by others. Therefore, in what follows in this letter are comments which record my impression of aspects of the program which strike me as being rather central to any decisions to be made.

1. The Proposed Environmental Statement encompasses the activities of a proposed future large industrial complex not just a single installation or a group of similar installations. Further, such activities are projected over the next 45 years. Necessarily, in such projections large uncertainties in technical, economic and social matters must be accepted and to pretend otherwise is to ignore all past experience. Within this framework, I judge the Statement to be an excellent, balanced and reasonable description of our energy situation as it may develop in the years ahead and of the role which LMFBR's could play in meeting our energy needs to the year 2020, and if needed, for many years beyond.

   By and large, the PFES assumes that energy options for the future are essentially a question to be resolved by the USA for itself. Since some of the problems such as safeguards, uranium resource and waste disposal, clearly are not limited to our country the matter of international opinion on the LMFBR role should be explored and might cast additional light on such exercises as cost/benefit analyses.

2. My reading of the Statement and Comments suggests that the following are technical issues which are of most concern; The Core Disruptive Accident; Plutonium Hazard; Plutonium Safeguards and Waste Disposal. Cost/Benefit Analyses are also prominent in both pro and con statements, but I believe, the range of projected costs and projected reactor performance are such that cost/benefit results can and probably will remain controversial until commercial operation is seriously contemplated, and commercial operation will not come about without the successful operation of a demonstration power plant and the completion of some of the necessary development work. This dilemma cannot be resolved by paper studies although they are useful in helping individuals form an opinion on the subject. This same remark applies to other electricity generation options frequently mentioned.

   Recognizing these uncertainties, the PFES does a competent job of cost/benefit analysis, and I believe, the results quoted are a conservative estimate of the benefits to be gained from the use of LMFBR's.

3. My comments on the technical matters mentioned in (2) above are as follows:

   (a) Core Disruptive Accident

   The central fact here is whether the probability that a rearrangement of core geometry producing a non-containable mechanical energy release is low enough to be acceptable to the public. What might be acceptable is conjecture but the discussion in the PFES suggests it is much less than 10-7 per reactor year. Of course, what energy release can be completely contained depends on design and on cost. The PFES correctly points out that a specific design of reactor and containment are required before the probability or consequences of an HCDA can be assessed and that no such design exists for commercial breeders or for the CRBR. The Statement concludes, however, that recent advances in analysis show that for large LMFBR's both the probability of occurrence and consequences of an HCDA are much smaller than previously estimated. Finally, it is stated that with a rapidly acting control system no serious core damage can occur and that the reliability of the control system is guaranteed by requiring two completely independent control systems of different design either of which is capable of shutting down the reactor. More detailed discussion of the mechanical and electrical features of such independent systems would, I believe, be effective in providing assurance that the risk of widespread radioactive contamination from

LMFBR's is indeed very remote. In addition, it would be very helpful to have a Wash 1400 type of analysis for both the CRBR and a commercial size LMFBR directed specifically to the HCDA. Detailed designs are required which cannot be produced for some time which again points up the fact that commercial use of the system follows successful R & D and Demonstration Reactor Programs and that we would not need such programs if we now had all the answers for commercial use.

One other point about the probability of HCDA. The technical background necessary to fully understand all the elements which enter into an assessment of the situation will be possessed by relatively few individuals so the layman must depend upon opinion of "experts" for guidance. The Nuclear Regulatory Commission and the associated ACRS were created specifically to provide such expert guidance. It is disconcerting to note that nowhere in the adverse comments to the PFES is there any expression of confidence that the NRC can be counted upon to protect the public from unacceptable risks. No large scale commercilization of LMFBR's will come about unless the experts of the NRC are convinced that the probability of damaging reactor accidents is sufficiently low. It would appear that some public education along these lines is badly needed: it is a public relations matter that should be of some concern to NRC.

(b) Plutonium Hazard

A great many pages of the PFES are devoted to advancing or disputing the claim that a new order of magnitude of radioactive hazard will be experienced if plutonium becomes a fuel for reactors. This is not a problem unique to the LMFBR but includes all reactor systems with any appreciable content of fertile material. It applies especially to the recycle of Pu to the LWR's. Construction and operation of the CRBR will not add materially to the problem (assuming that the question of HCDA is laid to rest by licensing) and so approval of the CRBR should not hinge upon a resolution of the Pu hazard question.

The PFES presentation makes a good case for dismissing the "hot particle" concept as not tenable and the many years of experience in handling PU without apparent untoward effects is reassuring. More research in this area clearly is needed so that the difference of opinion of about 10^5 in the tolerable exposure can be resolved. It seems to me, the weight of expert opinion supports the PFES position.

(c) Safeguards

The question of safeguarding plutonium (and other fissile isotopes) against theft or seizure by terrorists has become an issue generating much discussion, some of which is quite emotional. The PFES position is that safeguard measures have been adequate in the past and are being strengthened. For the future it is proposed that additional measures are available which can guarantee that even the large number of shipments of unirradiated fuel containing Pu contemplated for commercial LMFBR's can be safeguarded. It seems to me that what level of effort is required for this task is a matter to be determined by law enforcement experts who should be in a much better position to evaluate risks than the ordinary person. The PFES estimates the cost of an elaborate security system and concludes that it is acceptable.

Co-location of facilities would greatly simplify safeguards for some steps in the fuel cycle and if the common location included reactors the transportation risk essentially could be eliminated. Probably the first step in this direction should be location of fuel reprocessing and fuel fabrication at the same site thus eliminating off-site shipments of small packages containing undiluted fissile isotopes. Co-location will become still more attractive if commercial LMFBR's operate with turn-around fuel cycles considerably less than the 365 days or more assumed for the model plant.

Clandestine theft of small quantities is being made difficult by detection techniques and by much improved inventory checks for the reprocessing and fuel fabrication plants. Quantity imput to the chemical reprocessing plants is still not established as precisely as one would like but the theft of material from the head end of a reprocessing plant is made very difficult by the intense radioactivity. In my opinion, the safeguard question can be resolved with cost and risk at acceptable levels. As is noted in the PFES this is not just a U.S. problem but applies to all countries operating fission reactors.

(d) Waste Disposal

The PFES proposes to buy time to develop methods for permanent disposal by using for some years a retrievable surface storage facility. Apparently, ERDA recently has abandoned this concept and proposes to move directly to some form of disposal in geologic formations which would meet the requirements of permanent disposal. Bedded salt is only one of the methods being considered. Hopefully, this more optimistic approach will come into practice relatively soon otherwise the future of any nuclear power plants in this country will be in jeopardy. Such permanent disposal should include the trans-uranics since schemes to separate them and burn them in reactors adds another level of complexity to what already is complex enough. I applaud the effort to solve the problem now and I also doubt that the scheme of retrievable surface storage could be reintroduced. International cooperation on waste disposal studies and experiments is obviously desirable and should be pursued by ERDA.

4. The PFES discusses at some length possible alternatives to fission reactors and in particular to theLMFBR. Fossil fueled power plants based on our large reserves of coal clearly can meet future requirements but the economic and environmental cost probably are high.

Of the other alternatives Solar and Geothermal stand out both in PFES and reviewers comments as the best hope for the period to the year 2000. Fusion is the bright hope for later years. Yet none of these technologies has demonstrated technical capabilities to do the job whereas the LMFBR in a technical sense is a sure bet. This argument, it seems to me, justifies pursuing the LMFBR at least through the demonstration reactor phase. This will take 10 - 15 years to complete and, if at that time other options clearly have come through, a new look at the situation can be taken. However, if the Breeder is not pursued vigorously now, I believe, that the inevitable long delay in getting a program started again will accelerate the slide of the country into the variety of ills which are expected to result from an energy short economy.

Geothermal electricity generation certainly is possible in those areas where wet resources are available and should be exploited to the fullest extent consistent with cost and environmental impact. However, only the hot dry rock concept promises power available everywhere. Since experience with hot dry rock is lacking we have no reason to be optimistic. At issue seems to be the ability to create sufficient heat transfer surface in the rock <u>per well</u> to justify the concept. I doubt that creating the necessary surface with nuclear explosives will be acceptable to the public even if shown to be technically feasible. The proposed experimental program should be fully supported so that results will be in hand on a timely basis.

Electricity generation from Solar Energy by means of thermal conversion, in my opinion, is not a viable alternative to nuclear power. I believe the situation as described in Volume 111 is factual and gives little hope for solar energy via thermal conversion in the populated areas of our country.

The situation for photovoltaic conversion is similar except that the possibilities for invention are much better either in the basic cell or in mass production techniques. A real break-through in this area can be imagined and would make solar energy a viable competitor to nuclear power.

The ERDA program for fusion is well funded and is receiving vigorous management attention. It is hard to see what more can be done to advance the date when feasibility will be established. In any case, it is unlikely that fusion can contribute substantial amounts of power before well into the next century as the PFES suggests.

The PFES is a unique document since it brings together in a single format a substantial review of a number of technologies and especially, in the large number of references, provides a convenient and up-to-date source of information.

Permit me to make a final comment. Conservative estimates of fuel cycle costs for the LMFBR are at least as low as the costs for the LWR at the present time. But, the LWR costs will rise due to the rise in costs of U_3O_8 to $100 a pound and more. The LMFBR fuel cycle costs will remain low - less than 2 mills / kw-hr. Thus, the LMFBR is the only proven means of keeping fuel costs low for the indefinite future. Our own estimates and foreign experience indicate that capital costs of the LMFBR are within an acceptable range. I believe that the goal of providing long term low cost fuel for ourselves and for other nations will contribute greatly to our future well-being, and is well worth the expenditures contemplated by the LMFBR program.

Yours truly,

Walter H. Zinn

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May 23, 1975

Dr. Robert C. Seamans, Jr.
Energy Research and Development Administration
300 Seventh Street, Southwest
Washington, D. C. 20545

Dear Dr. Seamans:

This letter is in response to Dr. Frei's request for my comments on the LMFBR Environmental Impact Statement. Though I was asked to comment specifically on the nuclear alternatives and on the fuel cycle and waste management, I shall offer some more general observations, both on the EIS and on the breeder program.

General Observations

1. The LMFBR Environmental Impact Statement is a remarkably complete compendium of nuclear energy. It will serve for many years as an excellent summary of the state of the technology as of 1975.

2. The tone of the EIS is too defensive. Though I have not read all of it, I have not come across any place in the statement where AEC concedes that the intervenors have a substantial point. Yet some of the issues - for example, the long-term management of wastes - are clearly moot and will probably always remain so. The EIS would be improved if the strength of the intervenors' positions were conceded in those cases where questions are still unresolved.

3. The EIS seems not to confront fully the implications of a very large commitment (say 500 to 1000 plants) to LMFBRs, though it justifies the LMFBR on the grounds that such a large commitment is needed if energy from fission is to remain important after, say, 2020. I believe there is a basic inconsistency in the EIS in this respect: the statement would be stronger, or at least more consistent, if it tried to visualize the implications of the full-blown LMFBR deployment, not simply the implications of a single plant, or a few plants.

4. My own view of the LMFBR commitment is rather different than the one implied in EIS. I view the effort as a vastly important experiment that, however, does not necessarily lead to a viable, commercial industry. Whether LMFBRs can be the basis for a truly commercial industry still remains to be seen. In particular, it is absolutely necessary that the fuel cycle be closed.

5. I personally believe that alternatives to LMFBR should be retained; my reasons for so believing are summarized in the accompanying paper which I presented at the round table discussion on breeders before the European Nuclear Conference in Paris April 22, 1975.

6. Related to the last two points is the matter of how long we have until we need breeders. The EIS projection calls for "commercial introduction" of the breeder in 1987. The AEC energy demand projection used in the EIS is some 14 percent higher than the FEA Project Independence projection for 1985. A case can therefore be made for our taking more time to get the breeder.

My own view is, since we do not really know when we shall need the breeder, prudence dictates that we develop the technology as fast as we can, but make no commitment to commercialization until we know more about how successful the entire enterprise appears to be.

7. The EIS in a sense tends to underestimate the full significance of a successful breeder. The uranium content (at 3 ppm) of the rock underlying the U. S. to a depth of one mile is closer to 150×10^9 tons than the 1.8×10^9 tons quoted in the Environmental Impact Statement for granites containing 4-10 ppm. If Th is added to this (10 ppm), the figure is 600×10^9 tons. The net energy balance at 3 ppm is still positive by a factor of two or three. Thus, the breeder can tap essentially as large an energy source as fusion based on Li. The full very long-term significance of the breeder seems not to be recognized fully in EIS. As I think of justification for demonstrating the breeder fully, I keep coming back to this major attribute: the breeder taps an all but inexhaustible source of energy, and at a price we can estimate fairly well once the full demonstrations are made.

I realize that this is perhaps a philosophic point: but much of the cogent criticisms of nuclear energy and of the breeder are also very long range and philosophic. I would much prefer to rest the case for the breeder on its capacity to tap an inexhaustible source of energy, and concede that in exchange for this all but incalculable advantage we shall have to live with certain risks.

There is an important short-term consideration. At present the debate centers around urgency of the breeder. The anti's think we can afford to wait - long enough to see whether alternatives (fusion, solar) may prove out; if they do not prove out, they say, we won't have lost anything by waiting. The pro's (while conceding that commercialization by the mid-90's is probably acceptable), still feel we have none too much time, even to achieve that goal. My own view is that prudence requires us to move as rapidly as possible.

Finally, the EIS, as indeed does the reactor industry, makes the implicit assumption that breeder reactors must be compatible with the existing structure of the utility industry. I am not convinced that this is really the case. If, for example, co-location or nuclear parks were really decided on as a national policy, then it is quite likely that the utility industry will have to accommodate to the breeder technology, rather than the other way around.

Specific Issues

A. Alternative Nuclear Options

1. In general, these are fairly stated. The major weakness is the discussion of CANDU. The EIS leaves the impression that CANDU will be harder to license than LWRs, and that the changes necessary to make it licensable are very difficult. I find this discussion quite unconvincing. As far as commercial introduction of CANDU in the U. S. is concerned, the marketplace will decide this - probably within the next 10 years.

The CANDU-Th system is also dismissed too lightly. This system, like the LWBR, has the advantage of using "existing" technology. It has the disadvantage of not being a breeder, at least at what seem to be reasonable economics. I did not find a clear confrontation of these points in the Environmental Impact Statement.

2. LWBR - The main point here is that, after all these years, it is intolerable that LWBR technology is treated in secrecy, as though national security were at stake. The EIS gives a range of 1300 to 3000 tons of U as the 30-year commitment for a light water breeder reactor. I consider it disgraceful that, as far as I know, no one outside the LWBR program understands the LWBR sufficiently to check these numbers knowledgeably. Actually if the 1300 tons

is correct, LWBR could turn out to be a more serious competitor than most nuclear people would have thought possible a few years ago.

3. MSBR - This is a good summary. My own recommendation is to take MSBR more seriously than is now being done. The implication in the discussion of both MSBR and GCFBR is that if they do not displace LMFBR before LMFBR becomes commercial they will never make it. This I believe is not borne out by the history of other technologies: jets replaced reciprocating engines, steam turbines replaced steam engines; the best burner reactor is yet to be determined. If, as I believe, breeder reactors will probably form the base for man's energy system far into the future, it is more - not less - likely that several breeder types should be examined exhaustively.

B. Waste Disposal

1. As I understand the situation, ERDA has decided to abandon plans for above-surface waste depositories. The discussion of waste disposal in EIS is therefore a little beside the point.

2. I personally agree with the view that nuclear should not go ahead unless a permanent solution for wastes is developed. To this extent, I believe the intervenors are right. However, I believe AEC is wrong in denying that bedded salt is an acceptable method of permanent disposal. I do not believe any of the objections to bedded salt - intrusion of water, cracking of overburden, migration of plutonium - are valid. One of the most compelling bits of evidence as to the migration of Pu comes from the natural reactors in Oklo, Gabon. There are strong indications that at least 90 percent of the Pu remained in place, even though the plutonium was formed 2×10^9 years ago. I believe this observation should be made an important part of the Environmental Impact Statement on waste disposal.

3. The EIS should state more clearly what the ultimate capacity of salt is - how many reactors for how many years can be accommodated.

C. Fuel Cycle

1. A major weakness of the LMFBR program is the lack of a fully demonstrated reprocessing cycle. This point was made by Franklin of the United Kingdom at the European Nuclear Conference: he insisted that reprocessing of highly irradiated fuel poses new problems

whose solution is not readily apparent. The Johnson Foundation-Cornell University conference at Wingspread May 14-16, 1975 corrobated my belief that the fuel recycle is desperately in need of attention. The Environmental Impact Statement does not recognize this situation realistically.

2. In discussing contamination of land by Pu because of routine emissions from the chemical plant, the EIS should give integrated contamination after much longer periods of time - say 50 years, 100 years, 500 years. This is one of the touchiest problems: will the widespread use of Pu lead to gradual contamination of particular areas?

3. This is one reason why co-location of nuclear reactors seems like a good idea: to reduce and isolate the area that can conceivably be affected by operation of LMFBR and its supporting facilities.

4. In general, one gets the impression that the accident analysis for the chemical plant is nowhere near as detailed as the one for the reactor.

Concluding Remarks

As I have already said, the LMFBR Environmental Impact Statement is a remarkably complete estimate of where nuclear energy stands today, and where it is likely to go in the future. Its tone is, on the whole, too defensive; and it gives too much the impression of trying to support existing positions.

As for my own recommendation as to what should be done in the breeder program, I would urge:

1. All possible speed with LMFBR, but make no commitments about "commercialization". This would mean, first, finishing and operating FFTF as fast as possible. As for the Clinch River Breeder Reactor, we are in an inconsistent position. FFTF was supposed to provide information for CRBR. Instead, we build both simultaneously. This is hardly justified by pure logic; yet I am reluctant to recommend deferral of CRBR largely because the program would lose too much momentum by such deferral. If CRBR is not funded, a large steam generator facility must be built in its stead, and the opportunity taken to streamline and rationalize management of the project along the lines recommended to you by H. G. MacPherson.

2. All possible speed should be made with fuel recycle.

3. Keep the alternative breeders alive seriously.

A program such as this would certainly be viewed as a "technology" program; and it would meet criticisms of those who are unprepared to go totally on LMFBR, but who are prepared to bring the technology to full development. If FFTF, CRBR, and recycle are successful, "commercialization" will largely take care of itself.

I make this point because in some of the Congressional hearings there is a general acceptance of the idea of developing the technology, but less acceptance of the idea of a full-fledged commercial commitment. I submit that building CRBR, demonstrating recycle, keeping other breeder options open is a prudent approach to the technology. Yet, it does not pre-empt the question of commercialization until after some of the returns are in.

Sincerely yours,

Alvin M. Weinberg

Alvin M. Weinberg

AMW:bc
Enclosure

Round Table Discussion

on

THE ROLE OF THE BREEDER[1]

Remarks
by
Alvin M. Weinberg

(1) The breeder is important as a means of conserving uranium resources. Therefore in choosing the kind of breeder that best conserves our uranium resources, one must consider not only doubling time, but also the conservation coefficient. This is the product of breeding gain times (specific power)^2. In a breeder power system whose size is increasing linearly with time, the total amount of uranium ore that must be mined for such a power system is inversely proportional to the conservation coefficient. Specific power enters the conservation coefficient as the square. Thus a fivefold advantage in breeding gain in fast breeders (0.25 compared to .05) is balanced by a 2.2-fold advantage in specific power of thermal breeders of the molten salt (or oxide slurry D_2O) type. If Mr. Franklin's predictions prove correct - and the cooling time before reprocessing is several years for highly burned up oxide - then the specific power of the LMFBR may be reduced by perhaps a factor of two, which means that the conservation coefficient of the MSBR becomes relatively more favorable.

(2) Thorium is three times as abundant in the earth's crust as is uranium. Let's use it.

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[1]Presented before the Paris Nuclear Conference, April 22, 1975.

(3) I have maintained, and shall always maintain, that the all-but-unilateral commitment at this stage of the technology to a single line of breeder development is imprudent. We speak of the maturity of nuclear energy; yet, there are six separate converter systems still in contention: PWR, BWR, CANDU, HTGR, SGHWR, and the Russian graphite-moderated, light-water-cooled system. But when confronted with the much harder task of the breeder, we make an all but unilateral commitment to a single system, the Liquid Metal Fast Breeder Reactor; and we make that commitment before we have really demonstrated an essential step in the cycle: reprocessing. Drs. Angellini, Giraud, and Moulle suggested 1990 as the year of introduction of breeder. I suggest that these 15 years could well be used to develop several alternatives to the LMFBR.

(4) Most speakers seem to view fission as an interim energy source, to be replaced by fusion. I submit there is little hard evidence for this position: the strong possibility is that fission breeders will become man's ultimate energy source. From this long-range viewpoint, we cannot reject alternatives to LMFBR because of contention that "there is too little time".

(5) The alternative I most favor is the Molten Salt Breeder Reactor (MSBR), though I believe the world really has resources to examine several other alternatives seriously. MSBR is now being supported as a technology effort in the U. S. The most recent experiments suggest that Tellurium-induced intergranular cracking can be kept under control by small additions of Ti to nickel-based Hastelloy N. The quite remarkable continuous operation of MSRE

(2.5 years fuel salt circulation, 1.5 years equivalent full power) suggests to me that fluid fuel reactors can be made to operate reliably.

(6) My basic plea is for diversity: the breeder is too important to be pre-empted prematurely by one particular reactor type. The problems of fluid-fuel reactors are very different from those of solid-fueled reactors. If one concedes the advantage of diverse approaches to the breeder, then I suggest the arguments for serious pursuit of the fluid fuel system remain as compelling today as they were when first proposed at the 1955 Geneva Conference.

Rand
SANTA MONICA, CA. 90406

DONALD B. RICE
President

The Honorable Robert C. Seamans, Jr.
Administrator
Energy Research and Development Administration
Washington, D.C. 20545

Dear Bob:

This letter responds to your request for an independent review of the cost-benefit analysis of the liquid metal fast breeder reactor (LMFBR) contained in the Proposed Final Environmental Statement (PFES: WASH-1538, Vol. 4). Because no new research could be carried out in the time available, I have depended for the most part on existing studies and publications as well as on past Rand experience with the study of advanced-technology systems.

I have been assisted in my review by Professor Alan Manne and Richard Richels of Harvard University, James Plummer of NSF, and, extensively, by Arthur Alexander of Rand. The conclusions expressed, however, are those I have reached myself; the others do not necessarily subscribe to all of them.

My principal conclusions are summarized below, followed by a more detailed discussion.

<u>Summary of Findings</u>

This review of the cost-benefit analysis of the LMFBR is in three sections, each of which looks at the issue from a somewhat different perspective. The first section examines several of the most important assumptions and detailed projections which underlie the analysis. Section II reviews the role of cost-benefit analysis as a tool for decisionmaking in the LMFBR case, based on the analysis contained in the PFES and on the modifications suggested by our review. Based on a synthesis of these findings, the third section suggests some guides for future policy.

The findings in brief:

- o Capital cost differentials between LMFBR and LWRs are likely to be substantially higher than \$100/kW, based on learning curves applied to present estimates of the Clinch River Breeder Reactor (CRBR) and and Near Commercial Breeder Reactor (NCBR).

- R&D costs may go much higher than the PFES estimate of $5 billion (discounted), based on LMFBR program experience to date and evidence from Rand studies of defense R&D.

- The growth of demand for electrical energy over the next 10-15 years will almost certainly be slower than assumed in the PFES; demand in 2020 could easily be half of that postulated in the base case predictions, based on independent estimates with price effects included.

- Several circumstances adverse to the LMFBR are likely to occur in concert, substantially reducing net benefits from the PFES "base" case (in contradiction to the study's conclusion [11.3-1]).

- Net benefits are not very sensitive to the LMFBR availability date (in contradiction to the study's conclusion [11.2-5]).

- The great uncertainties that characterize both the program and the economic environment in which it is embedded can be effectively met only with an austere, incremental, sequential development program, with adequate time for test and evaluation, and with a plan for resolving uncertainty over time.

- A slimmed down, sequential program may be acceptable to proponents and opponents if confidence and trust are established through frank and open public program reviews by ERDA.

I. REVIEW OF ASSUMPTIONS AND PROJECTIONS

In a work as detailed, voluminous, and basically well done as the PFES, I could naturally select only a few points to review and comment on. However, two specific areas critically affect the predicted net benefits of the project -- capital cost differentials between the LMFBR and light water reactors, and R&D costs. There is reason to be concerned with their treatment in the PFES. In addition, I propose to comment on the appropriate discount rate and to review a number of estimates of near term electrical energy demand growth that deviate from assumptions in the cost-benefit analysis.

Capital Cost Differentials

The capital cost estimate of $520/kW at "initial commercial introduction" of the LMFBR is not a credible figure and introduces considerable doubt about the early

$100/kW differential of the LMFBR over the light water reactor (LWR). The AEC used an engineering cost model (based on unknown assumptions as to the maturity of the LMFBR technology) to derive this low capital cost, which would be only 24 percent higher than the projected $420/kW costs of a mature LWR in 1987. One relatively firm piece of information is inconsistent with these calculations -- the design costs of the Clinch River Breeder Reactor (CRBR). These costs can be used in conjunction with empirically established learning curves to develop future LMFBR capital costs.

The current construction cost projection for the CRBR is $1.2 billion[2] for 350 megawatts -- giving a capital cost/kW of more than $3400. Similarly, rough estimates for the reactor to follow the CRBR -- the NCBR -- predict capital costs in the region of $2000/kW. But since neither of these plants has been built, both of these figures are conjectural and may, in fact, be too low. Applying a 90 percent learning curve to initial costs of $2000 and $3000/kW suggests that LMFBR costs will be much larger than LWR costs until at least year 2020.[3] If LWR capital costs fall by 1 percent per year as a result of productivity growth and technological change, a 90 percent learning curve applied to $1000, $2000, and $3000/kW initial costs does not bring down future costs far enough to meet the slowly falling LWR costs (see Table 2 and Figure 1).[4] Only for an 80 percent learning curve will LMFBR capital costs become equal to LWR costs -- in 1990, 1999, and 2020 for the $1000, $2000, and $3000 initial cost cases, respectively. Experience suggests that cost reduction at this fast rate is quite unlikely.

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[1]Learning curves are empirically based relationships in widespread use to project the reduction in unit costs associated with each doubling of cumulative quantity produced. A 90 percent curve means that the cost of the last unit produced is reduced by 10 percent when quantity produced is doubled. See Table 1 for examples. Typical learning curve values in other fields are 78-85 percent for airframes, 90-92 percent for aircraft engines and rocket motors, 95-98 percent for electronic systems. See H. Asher, <u>Cost-Quantity Relationships in the Airframe Industry</u>, The Rand Corporation, R-291, July 1956, for a discussion of the theory and application of learning curves.

[2]GAO Report on LMFBR, April 28, 1975.

[3]The cost-benefit analysis uses a 98 percent curve, but claims that a 90 percent relationship was characteristic of LWRs [11.2-84 and ERDA Staff Statement, May 27, 1975, p. 19]. French studies also conclude that learning curves from 87-92 percent have been experienced with LWRs [11.2-91].

[4]In the calculations of Table 2 and Figure 1, we rely on the PFES' highly optimistic assumptions of early introduction date and rapid production rate of commercial LMFBRs. The first few lines of page 11.2-134 indicate that the authors of the PFES may doubt these assumptions.

6

Table 1

EFFECT OF LEARNING PROCESS ON PRODUCTION COSTS OF LAST UNIT, FOR ALTERNATIVE LEARNING CURVE ASSUMPTIONS.

A DOUBLING OF NUMBER PRODUCED REDUCES UNIT COST OF LAST ITEM TO SPECIFIED PERCENTAGE.

Units Produced	Marginal Cost of Last Unit as Proportion of Cost of First Unit With Learning Curves of:			
	95%	90%	85%	80%
1	1.0	1.0	1.0	1.0
2	.95	.90	.85	.80
4	.90	.81	.72	.64
8	.86	.73	.61	.51
16	.81	.66	.52	.41
32	.77	.59	.44	.33
64	.74	.53	.38	.26
128	.70	.48	.32	.21
256	.66	.43	.27	.17
512	.63	.39	.23	.13
1024	.60	.35	.20	.11

IV C-20

Table 2

CAPITAL COSTS PER kW OVER TIME WITH OPTIMISTIC INTRODUCTION SCHEDULE AND ALTERNATIVE LEARNING CURVES AND FIRST UNIT COSTS

Year	Cumulative Units Produced	Capital Cost/kW at Specified Initial Costs and Learning Curves					
		$1000/kW Initial Cost		$2000/kW Initial Cost		$3000/kW Initial Cost	
		90%	80%	90%	80%	90%	80%
1986-87	1	1000	1000	2000	2000	3000	3000
1988-89	9	716	494	1432	988	2148	1482
1990-91	22	625	370	1250	740	1875	1110
1992-93	46	559	292	1118	584	1677	875
1994-95	80	514	244	1028	488	1542	732
1996-97	126	480	211	960	422	1437	633
1998-99	186	450	186	900	372	1355	558
2000-01	252	430	169	860	338	1293	507
2002-03	352	410	151	820	302	1230	453
2004-05	462	390	139	780	278	1182	417
2006-07	560	380	130	760	260	1146	390
2008-09	670	370	123	740	246	1116	369
2010-19	1178	340	103	680	206	1023	309

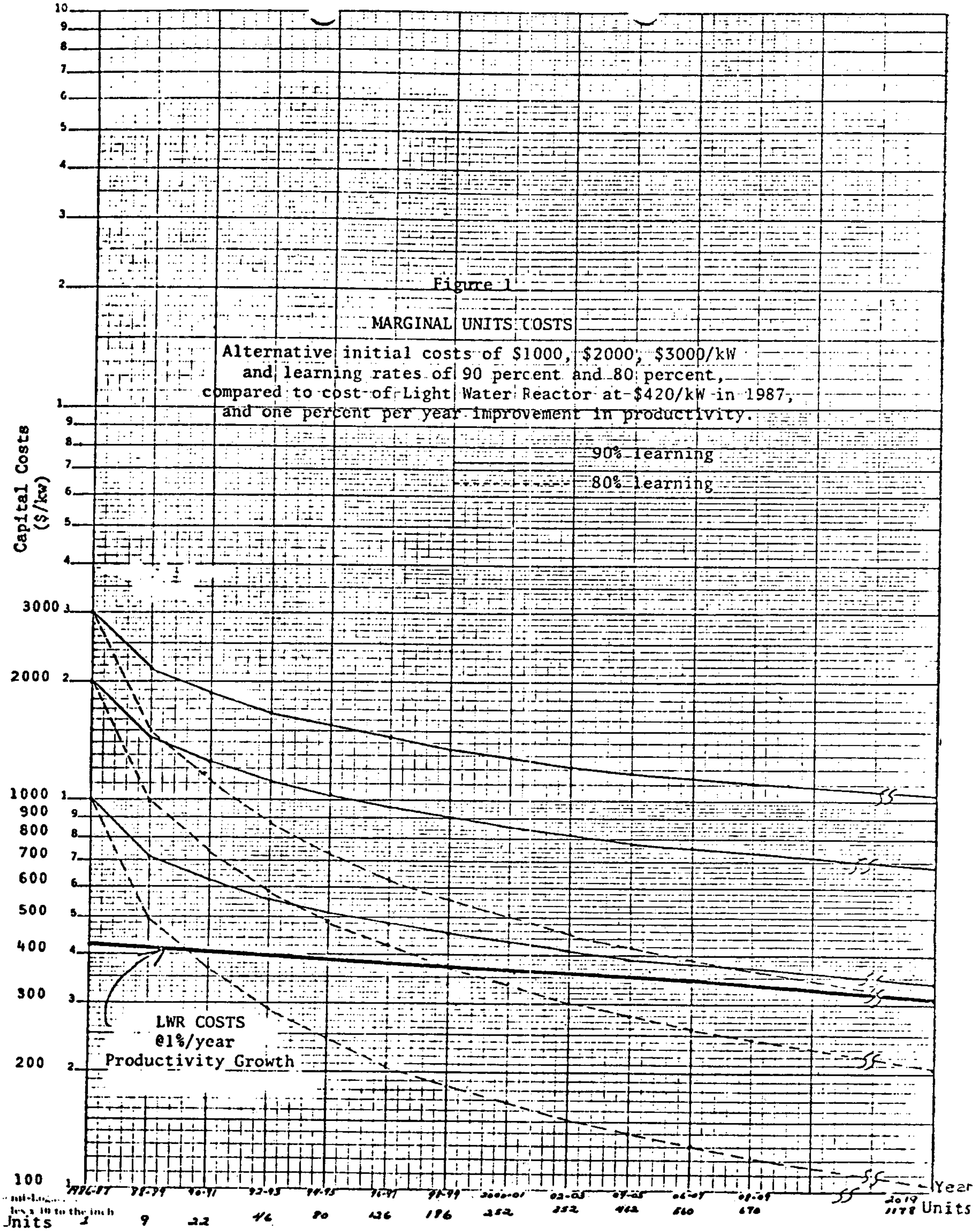
Figure 1
MARGINAL UNITS COSTS
Alternative initial costs of $1000, $2000, $3000/kW and learning rates of 90 percent and 80 percent, compared to cost of Light Water Reactor at $420/kW in 1987, and one percent per year improvement in productivity.
90% learning
80% learning
Capital Costs ($/kw)
3000
2000
1000
900
800
700
600
500
400
300
200
100
LWR COSTS
@1%/year
Productivity Growth
Year
Units
2019

Let me emphasize that so far we have been speaking only of marginal costs -- that is, the cost of the last unit. Average costs will be considerably higher since they are calculated over all the earlier, higher-cost units. The average cost of 1000 units with a 90 percent learning curve and $1000, $2000, and $3000 per kW initial costs would be $410, $820, and $1230. Of course, the assumption of a 1000 unit "production run" may be quite optimistic; average costs would be higher for lower quantities.

The PFES assumed that, except for the more rapid learning effects in the LMFBR because of its relatively less mature status, productivity increases in LWR plants and other shifts in generating costs will parallel those in LMFBR plants. This assumption rules out independent productivity gains by established technologies -- it ignores the steady, non-transferable productivity increases over the years that result from construction and operation of plants of a given type. However, major shifts in costs due to economy-wide forces, such as environmental considerations, would affect generically similar equipment in a parallel fashion, as assumed by the PFES. Several studies of steam-power electrical generating plants show capital costs falling over many decades at a rate that is somewhat faster than average U.S. productivity gains. (This equipment is also more efficient in its use of fuel and labor inputs.)[1] Inflation-adjusted costs of both fossil and nuclear plants, though, began to rise in 1970, the apparent result of economy-wide forces stemming from design changes required by tighter environmental standards and from an overextended construction industry in which prices were rising faster than overall inflation and productivity was deteriorating.[2] The upturn in generating costs is unlikely to continue indefinitely into the future. When design standards for safety and pollution stabilize, the long term historical trend in productivity improvement should resume. This assumption is reflected in the 1 percent annual productivity increase for LWR plants shown in Figure 1.

I conclude from the above that the $520 capital cost figure for initial commercialization of the LMFBR is highly unrealistic -- given what we know about CRBR and NCBR. Capital cost differentials are likely to be considerably higher than even the worst case calculation in the PFES. Since LMFBR capital costs at the base case level of $520 are approximately two-thirds of total bus bar electrical costs, our calculations imply substantially higher electrical costs than assumed in the PFES. LMFBR technology that is not competitive with either LWR or fossil fuel generators is thereby implied.

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[1] See, for example, Yoram Barzel, "The Production Function and Technological Change in the Steam Power Industry," Journal of Political Economy, Vol. 72, April 1964.

[2] See, Irvin C. Bupp, et al., "Trends in Light Water Reactor Capital Costs in the United States," Center for Policy Alternatives, M.I.T., September 1974; McTague, et al., Nuclear News, February 1972; Roe & Young, Power Engineering, June 1972.

R&D Costs

Research and development costs of the LMFBR could well be two to three times higher than those projected in the PFES. This conclusion is based on experience in the LMFBR program itself as well as on past Rand studies of the acquisition of high technology systems in the military and civilian sectors, both in this country and abroad.

The Fast Flux Test Facility has experienced a program cost overrun, over an eight year period, of from 500 to 1000 percent, depending on what is included in the initial and final estimates. Adjustment for inflation would not alter the basic finding that costs were several times greater than first anticipated and that schedules slipped by more than six years.

The Sodium Pump Test Facility, from first estimates in 1966 to actual results in 1974, experienced a cost growth of 300 percent (unadjusted for inflation) for a sodium pump capacity that was only one-third of that originally planned. Modifications to increase pump capacity would increase costs to more than eight times original estimates (unadjusted).

In the three years since 1972, cost estimates for the Clinch River Breeder Reactor have climbed from $700 million to $1.77 billion. This growth factor of 250 percent over a three year period is based on design studies only -- construction of the plant has not yet begun.[1]

General Electric's Midwest Fuel Recovery Plant, intended to extract uranium and plutonium from exhausted nuclear fuel rods, was expected to cost $36 million in 1968 when construction began, with a completion date set for mid-1970. By 1974, costs had risen to $64 million and the plant did not work; current plans are uncertain, but the plant may be abandoned or scrapped. Redesigning and rebuilding the facility would be expected to take four more years with additional expenditures of $90 million to $130 million.[2]

These are perhaps extreme statements of cost growth trends because they extend from very preliminary first estimates -- which are characteristically optimistic -- rather than from estimates based on careful engineering and statistical cost analyses. Nevertheless, studies of major weapon systems indicate that cost overruns are proportional to the degree of technological advance sought in a project.[3] Resolving

[1]These three cases are summarized in, "The Liquid Metal Fast Breeder Reactor -- Past, Present, and Future," by the Comptroller General of the United States, General Accounting Office, RED-75-352, April 1975.

[2]See, "Nuclear Fuel Reprocessing: GE's Balky Plant Poses Shortage," Science, Vol. 185, 30 August 1974.

[3]Robert L. Perry, et al., System Acquisition Strategies, R-733-PR/ARPA, The Rand Corporation, 1971.

major technological uncertainties is usually more costly than anticipated. The natural optimism of program advocates often tends to obscure the realities of state-of-the-art advances actually required in a program. To project engineers, a technological feature that is conceptually well in hand is often treated as being "on the shelf." The ERDA staff, for example, concludes that "the LMFBR is a well-advanced technology which has reached the demonstration plant stage."[1] This enthusiastic and optimistic attitude, while understandable and often even commendable, makes risky projects seem sure things -- a process that usually increases the probability of project failure. The nuclear plant experience cited above should serve to dampen such confidence.[2]

Cost growth caused by pushing the technology is compounded by the added uncertainty of prediction made over lengthy periods.[3] As information is generated through the construction and testing of a system, cost predictions become more accurate. The length of time between R&D cost predictions and the expected completion of facilities can exceed ten years. The effect is to multiply new technology cost growth by a factor that grows exponentially with the prediction interval.

Given this history, it would not be a unique outcome if LMFBR costs rose to several times the current estimates, given the long time horizon over which they are projected. Indeed, some large increase in program costs should be expected and taken into account by decisionmakers. Section II will examine the sensitivity of benefit-cost calculations to discounted R&D costs at the PFES level of $5 billion and at higher levels of $10 billion and $15 billion. The third section discusses an alternative R&D strategy that treats the technological uncertainties in a more appropriate manner.

As an aside, the PFES treats a wide range of variability in factors affecting the benefit side of benefit-cost calculations, but does no analysis of cost. Variability in costs has great impact on net benefits, as Section II will show. A much more extensive analysis is needed of costs to illuminate the basis for the estimates and identify the sources of uncertainty.

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[1]ERDA Staff Statement, May 27, 1975, p. 4. This statement can be compared to a similar assessment by the Secretary of the Air Force before Congress in 1966 with respect to the development of the C-5A transport aircraft: "The C-5A is within the state of the art and we should have no great trouble in building it." In 1975, the GAO reported: "They [officials of the Military Airlift Command] explained that the C-5's major systems and subsystems, as well as the airframes, are extremely complex and that their designs are at the upper limits of the state of the art."

[2]A specific case of cost underestimation is the NCBR for which the PFES includes $276 million, surely far too low an amount for the government share.

[3]Alvin Harman, A Methodology for Cost Factor Comparison and Prediction, RM-6269-ARPA, The Rand Corporation, 1970.

Discount Rate

We have little to add to the voluminous literature on the appropriate discount rate except to comment on the treatment of the discount rate in the PFES.

The PFES uses discount rates of 10, 7-1/2 and 5 percent. I am persuaded by the literature and by analytical experience that the appropriate rate is at or near the high end of this range. The calculations based on 5 percent should be seen as having only arithmetic interest.

Contrary to the PFES, I do not agree that the conclusions turn heavily on the discount rate. Factors such as technological uncertainty, future electricity demand, capital cost differentials, uranium supply, and others not reviewed here have, in my view, more impact on and relevance to a decision on the LMFBR. It is not discounting that makes it difficult to reach a conclusion in favor of "full speed ahead" on the LMFBR but, rather, the location of the ranges of uncertainty on other key parameters.

Electrical Energy Requirements

Future electrical energy demand in the PFES cost-benefit analysis centers "around a case based on historical projection" [11.2-55], with total energy demand continuing to grow in relation to GNP much the same as in the last 25 years [11.2-53]. In particular, near- term growth over the next decade is expected to maintain past trends at about a 7.8 percent annual growth rate. From that point on, alternative growth paths are assessed until the year 2020. A critical section of the growth path is the early period where the base for future growth is established. A 7.8 percent growth trend over ten years would result in a level of electricity consumption that is 29 percent higher than the level for a five percent growth rate, and 42 percent higher than the level for a four percent rate. Even if projected growth after the first decade is reduced to the same low level for each of the initial alternatives, the differences established in the first decade will persist. Since this near-term future is close to recent experience, uncertainties in prediction should be relatively amenable to detailed analysis, whereas the long-term predictions are appropriately made with cruder tools.

Most of the independent analyses of future electricity demand have estimated early period growth rates considerably below the PFES base case, with consequent low consumption levels projected for future periods. The Environmental Protection Agency (EPA), citing Project Independence projections, calculates electrical energy demand for 2020 to be 28 to 33 percent below the PFES base case. They believe that even a 50 percent lower figure is a reasonable possibility.[1] The Federal

[1] Environmental Protection Agency, "Comments on Proposed Final Environmental Statement," April 1975, pp. 3, 10.

Energy Administration finds the PFES projection out of date and provides an analysis showing a 5 percent growth rate for the next ten years, and a 25 percent lower demand than the PFES estimate through 2000.[1]

Unpublished studies by National Economic Research Associates (NERA) project a ten-year growth rate of 5.5 to 6.5 percent.

Studies performed at Harvard allow energy demand to be determined endogenously within the model through a price elasticity.[2] Initial trials with this enlarged model suggest electrical demand in 2000 to be 50 percent below the PFES base case.

Milton Searle has estimated a range of growth rates through 2020. His high trend through 2000 yields a demand level for that year approximately one-third lower than the PFES base case.[3]

This catalogue of research results could be extended, but the implication is clear. Most independent analyses produce electrical energy growth rates more like the PFES "low" to "very low" estimates. The PFES "base case" should be considered quite high. As suggested above, many of the differences among these estimates can be traced to the near-term projections. Fortunately, the uncertainties of the next ten years can be reduced through better research and time, both of which ERDA ought to be buying.

II. THE COST-BENEFIT ANALYSIS AS A TOOL FOR DECISION

A major theme of the cost-benefit analysis and the PFES as a whole is the great uncertainty in a program as complex and extended through time as the LMFBR. The range of examined alternatives is sweeping. For many of the analyzed cases, there are substantial returns to the possession of a successful breeder technology. On the other hand, many cases exist for which the LMFBR would not be a paying proposition. Incorporating revisions to the analysis as suggested in the preceding section leads me to believe that the cost-benefit analysis in the PFES tends to be strongly biased in favor of the LMFBR.

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[1] Federal Energy Administration, Comment letter 89, May 1, 1975.

[2] Alan S. Manne, "Preliminary Results From Endogenous Demand Model Breeder Commercialization," unpublished paper, April 23, 1975.

[3] Milton Searle, Uranium Resources to Meet Long-Term Uranium Requirements, Electric Power Research Institute, September 1974.

The effects of revising the base assumptions are summarized in Table 3. The Table provides a count of the cases calculated in the PFES with benefits less than $5, $10, and $15 billion. The PFES estimates the discounted R&D costs at $5 billion. However, our discussion above suggested the $10 billion, or even $15 billion, are possible, perhaps likely, outcomes. For the 61 LMFBR cases[1] analyzed in the PFES, 15 (or almost 25 percent) predicted gross benefits below $5 billion, and 28 (46 percent) fell below $15 billion. From the total of 61 cases, Table 3 displays selected subsamples that illustrate the impact of the higher capital cost differentials and lower electrical energy growth discussed in Section I. In addition, an optimistic uranium supply condition was also included in Table 3 to illustrate the sensitivity of results to variations in that parameter.

With a capital cost differential of $100/kW between LMFBR and LWR plants, 15 out of 16 cases have gross benefits smaller than $15 billion, and 11 cases are smaller than $5 billion. When this high capital cost differential is combined with low electrical energy demand growth, the results are even more striking -- 7 out of 8 cases show benefits smaller than $5 billion. Both of these conditions, I believe, are more likely than the base case assumptions in the PFES.

In fact, I must point out that the $100/kW capital cost differential was used here only because these calculations were available, and not because the differential should be expected to be that small. If the differential were as high as $200 or $300/kW (as seems more likely), gross benefits would be commensurably smaller, and perhaps even negative. In the linear programming model used in the cost-benefit analysis, the introduction rate of the LMFBR was dependent on economic factors as the LMFBR competed with other energy sources -- unless constraints were imposed on the model. When a test calculation was made in which only the "early commercial" breeder was available (at, presumably $520/kW capital cost) and no constraints were imposed, the model "produced a small benefit" [11.2-132].

On this evidence, and on the evidence cited in Table 3, I would guess that, in an unconstrained case, higher cost differentials would make the LMFBR uneconomic. Nevertheless, all of the predictions are probabilistic and detailed predictions beyond 2000 border on the psychic.

Given the wide range of possible net benefits -- from large negative values to even larger positive values -- of what use is a cost-benefit analysis of the kind presented in the PFES? If the net benefit had turned out to be predominantly either positive or negative when future possibilities were assessed over the distribution of probable

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[1]To the 76 cases of Table IV.D-1 in the PFES were added three cases taken from Figure 11.2-11 (page 11.2-19), and three cases from Environmental Protection Agency, Comments on PFES, April 1975, Table 1, p. 18. Of these 82 cases, 21 were base case analyses without LMFBR. Therefore, 61 cases included gross benefits for possessing the breeder.

Table 3

SENSITIVITY OF COST BENEFIT CALCULATIONS
TO CHANGES IN ECONOMIC FACTORS

Case Selection Criteria	Number of Cases	Number of Cases (at 10% discount) with Gross Benefits Less Than: $15 Billion	$10 Billion	$5 Billion
All cases	61	28	23	15
Energy Demand: base case or lower	53	28	23	15
Uranium supply: base case or optimistic	43	20	18	13
Capital cost differential: +$100/kW	16	15	13	11
Energy demand: lower than base case and Uranium supply: base case or optimistic	35	20	18	13
Capital cost differential: +$100/kW and Uranium supply: base case or optimistic	10	10	10	9
Capital cost differential: +$100/kW and Energy demand: lower than base case	8	8	8	7

values, the analysis would provide a signal for a "go" or "no-go" decision. This review suggests that the outcome is much closer to the "no-go" end than does the PFES. Still, there is considerable uncertainty. The outcomes of the analysis do not permit opponents to condemn the project out of hand as uneconomic, or -- for that matter -- a prudent decisionmaker to commit the nation to an LMFBR economy.

The PFES cost-benefit analysis is not primarily a decisionmaking document, although, at least in revised form, it can contribute to the decision process. It reflects, rather, the perceptions and needs of those outside the LMFBR project. The requirements of the environmental impact statement call for the forecasting and evaluation of a highly uncertain future. The AEC tried to cope with these requirements by calculating hundreds of outcomes under varying assumptions. However, each scenario represents the uncertainties as though they were all resolved before any actual decisions have to be taken. To some degree, this approach derives from programmatic Environmental Impact Statement requirements, but it also reflects the actual LMFBR program plans.

The analysis conveys a strong impression throughout that it is important to decide now either to accept or reject an entire development program. For example, delaying LMFBR introduction by a few years is pictured as a case of all loss and no gain. But large positive benefits could result from delaying or extending the program; ongoing ERDA studies, research, and facility development during the period of delay would surely generate information that would lessen the potential for costly mistakes. Analyses performed by James Plummer and Richard Richels for the NSF Office of Energy R&D Policy indicate that the PFES portrayal of losses due to delay are unduly pessimistic. As one scenario, they incorporate a lower electrical growth path (beginning with 5.6 percent through 1985) and assume that total undiscounted R&D costs will remain constant if the program is delayed; however, discounted R&D costs fall as these expenditures are shifted into future years. The Plummer and Richels results can be interpreted to show that net discounted benefits are relatively insensitive to LMFBR availability dates over the period from 1988 to 2006. Thus, even within the restricted scenario structure of the cost-benefit analysis, there is evidence that a go/no-go decision is not necessary at this time.

For decisionmaking purposes, one could perhaps develop a better model of the actual development process through use of a probabilistic decision analysis. However, even a decision-tree analysis that explicitly treats the uncertainties of the program and the multiple potential paths that may be taken, may not be able to deal with the "strong uncertainties" that exist in a major R&D undertaking. That is, one must admit future possibilities that are inconceivable at present, whose probabilities cannot now be estimated. For example, a look back over the past seven years since the first LMFBR cost-benefit analysis was made shows two important, difficult-to-predict events, about which opinions were and continue to be significantly divided -- the large increases in fossil fuel prices stemming mainly from OPEC cartel actions, and the great impact of environmental concerns on the costs and plans for nuclear power. These events have critically affected the course of nuclear power. If over a seven-year period, two major new sources of uncertainty arose, consider the probability of other equally powerful and uncertain events arising over the next 25-40 years covered by the cost-benefit analysis.

In short, the cost-benefit analysis underlines the high degree of uncertainty surrounding the LMFBR and provides some understanding of how a wide range of future events may affect the economics of an LMFBR investment. Incorporating a set of modified assumptions that we believe are more likely than the base-case assumptions yields a high percentage of possible outcomes with low or negative payoff. The work by Plummer and Richels for NSF suggests that net benefits are not substantially reduced by a delayed introduction and commercialization of the LMFBR. All of these conclusions point to a policy that recognizes the uncertainty and is willing to trade time for knowledge. Section III discusses such policy approaches.

III. GUIDES FOR FUTURE POLICY

This section seeks to describe a strategy for decision rather than prescribe a specific course of action. The major features of a sequential development strategy are outlined first. Next, some of the impediments to such a policy are considered. Finally, techniques that may aid in implementing a sequential strategy are discussed.

It can be postulated that the purpose of a federal demonstration project encompassing great uncertainty in many dimensions is to reduce that uncertainty through the generation of validated information. The success of demonstration should therefore be judged by its efficiency in doing this job -- reducing the uncertainty -- and not by whether the technology is ultimately disseminated.

The uncertainties relate to several dimensions of this project -- technology, costs, demands, reliability, safety, licenseability, etc. A current Rand study of federal demonstration projects suggests that if the technological uncertainties are not well in hand, the ability of a demonstration to reduce the other dimensions of uncertainty is likely to be compromised. The first task, therefore, is to prove out the technology before proceeding to the next phases. Though I do not claim specific technical expertise on the LMFBR, the evidence seems to indicate that this first task has not yet been completed.

ERDA is conducting major studies to reduce many of the uncertainties. For example, over the next five years, the Natural Uranium Resources Evaluation Program should substantially increase our knowledge of domestic uranium availability. Even without special studies, new information is continuously becoming available that alters the analysis and outcomes of the LMFBR: "The principal difference between this cost-benefit study and previous cost-benefit studies is that the basic input data have appreciably changed... Because of this, a new study was required for this Environmental Impact Statement." [11.2-1]

Rand studies on technologically advanced systems have shown that austerely developed technical feasibility prototypes are highly desirable both for components and for the entire system before significant work is done to verify the other dimensions of the system.[1] The purpose of austerity is to force developers to use as much off-the-shelf technology as possible, to pursue new designs only where necessary, and to infuse the project with greater creativity and more astute engineering.

Many of the European breeder development programs have proceeded in an incremental, step-like fashion. The French have resisted commitment to a new phase until the reactor of the preceding phase was operating successfully. In Germany, the 20 mW sodium-cooled thermal reactor at Karlsruhe is being modified for operation as a fast reactor. The Soviet Union reworked a 100 kWt (kilowatts thermal) mercury-cooled plutonium reactor into a sodium-cooled plutonium reactor of 5 mWt power. This reactor was later modified for operation at 10 mWt. By changing as few things as possible at each new step, the uncertainties associated with each advance are reduced. Each specific design may not be optimal, but it works, and the sequence can lead to an optimal system design that works.

An essential feature of a sequential strategy is the learning that goes on between phases. Incremental design reduces the amount of testing and learning that must be done at each step. But it is vital that the test and evaluation phase not be ignored. Once again, this takes time; in weapons developments, the costs of not taking this time is measured in billions of dollars and reductions in effective force size. When time is not critical, as in the LMFBR case, it is a cheap commodity; and there have been very few instances where a rush to completion can be justified after the fact. For that matter, there is little hard evidence to support the assumption that incremental, sequential development is slower, in the end, than compressed, concurrent development. It is at least as safe to conclude otherwise.

To summarize, my recommendations for a sequential development strategy include: austere development; incremental design; and time to test. Faced with such a large degree of uncertainty, the prudent decisionmaker will (a) elect not to make decisions that can't be wisely made now (commitment to the currently proposed full develop-

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[1] Robert L. Perry, et al., System Acquisition Strategies, R-733-PR/ARPA, The Rand Corporation, June 1971; Burton H. Klein, et al., Military Research and Development Policies, R-333, The Rand Corporation, December 1958; L. L. Johnson, The Century Series Fighters: A Study in Research and Development, RM-2549-PR, The Rand Corporation, May 1960.

ment program), (b) make today only the decisions that must be made today (for example, key components of CRBR), and (c) plan for the resolution of uncertainty over time (uranium supply, electricity demand, capital costs, R&D costs, etc.). To put it another way, a program that requires a minimum of 12 years to complete is simply beyond human ability to preplan with such confidence that one would want to commit to all of it.

One final point about this strategy: if everything goes well as proponents claim it will, if all the uncertain parameters turn out as estimated in the PFES, and if all the technology is as well in hand as proponents contend, this strategy will result, with very high confidence, in a working, safe and economical breeder only a few years beyond 1987. If the PFES scenario is adopted and proves faulty in any major respect, the least unfavorable result would be significant schedule slippage and cost growth.

Why is such a strategy so difficult to adopt for large, U.S. government programs? Project proponents don't like a sequential process. It implies smaller budgets stretched out over time. It appears to complicate their task by comparison with the illusory alternative of commitment to a fully preplanned course. The project can be perceived as easier to kill if things do not turn out too well -- or even if they do -- because there are no large economic or political consequences linked to cancellation.

Project opponents don't like this kind of low-profile sequential decisionmaking, either. They view it as the camel's nose under the tent. The program can be perceived as hard to kill in the early stages because the major production decision may be years away and no important resource commitments will be up for review until then. The project can develop a constituency and momentum over time that will later roll over its critics.

Politicians may have other reasons for disliking the sequential approach. They may feel short on the expertise needed to evaluate program decisions year after year. Multi-billion dollar decisions are political decisions with high transactions costs to those involved.

Thus, many pressures converge to force a major program review into a take-it or leave-it framework.

Despite the difficulties in running a sequential development program, I believe that ERDA should implement such a strategy. The present situation has grown out of past decisions, promises, and habits that will be hard to change. A shift in direction at this point, however, can be viewed as the result of a frank appraisal of new information and analyses. A stance of openness before the Congress and the public will certainly help to gain their confidence and trust and, perhaps, their grant of authority to manage the program. Further, there is no need to sell the LMFBR now as a billion-dollar program. Rather it can be straightforwardly described as a step toward reducing uncertainty and averting risk for the future. This would require a retrenchment of goals and a slimming down of tasks, but that may be a rational response at the present time.

It must be openly acknowledged that much uncertainty exists in pursuing any new technology -- especially one, like LMFBR, that depends on world-wide events beyond the control of the project. A detailed future cannot and should not be promised; there is always the possibility that the resources spent in advancing LMFBR technology may not have the desired payoff. However, such efforts can be structured to enhance the probability of success and to reduce the cost of failure.

ERDA is of course now more than nuclear. A relative reallocation of resources within the agency, as implied by recommendations to scale down and stretch out the LMFBR, could enhance internal competition and foster more realism in estimates generated by intramural reviews and critiques. It should also be noted that a non-sequential process (which includes the option of cancellation) formally eliminates the possibility of learning, increases uncertainty by straight-jacketing the future, and increases the probability that costs (whether social or project) will be greater than necessary. That is, a truly sequential approach could turn out to cost less and take little, if any, additional time to attain the objective of a reliable, safe, and economical breeder system.

ERDA stands astride many technologies and many possible changes. Its actions today can have a significant impact on the future. Winning approval to carry out an LMFBR project as currently structured could be a Pyrrhic victory. A defeat could carry over to broader issues. A sequential strategy, honestly taken, periodically and critically appraised, with the goal of reducing uncertainty and generating validated information, can perhaps establish a course between these two equally undesirable outcomes.

Sincerely,

Donald B. Rice

Donald B. Rice
President

DBR:jy

cc: The Honorable Robert W. Fri,
Deputy Administrator, ERDA

EPRI

June 19, 1975

Mr. Robert C. Seamans, Jr.
Administrator
United States Energy Research
and Development Administration
Washington, D. C. 20545

Dear Mr. Seamans:

In response to your letter of April 3rd, I have reviewed the sections on health effects of the Proposed Final Environmental Statement - Liquid Metal Fast Breeder Reactor Program (WASH-1535). In particular, I have attempted to determine if the thrust of the conclusions of the health effects sections is in accordance with existing scientific data and the consensus of scientific judgment based on my experience as chairman of the NAS-NRC committee that produced the BEIR report on "The Effects on Populations of Exposure to Low Levels of Ionizing Radiation".

In my opinion, the conclusions are valid in that health or bioenvironmental impacts would not be of sufficient magnitude to have any bearing on the decision to proceed with, defer or abandon the LMFBR program.

One can take issue with various details of the health effects section and clearly there is more research to be done. There are still uncertainties in the quantitation of various important parameters: e.g. the amount of radioactivity released per unit of electricity produced; meteorological transport; the resuspension factor; dispersal in soil; root and foliar uptake by plants; inhalation and ingestion by the population; actinide metabolism within the body; induction efficiency of cancer and genetic defects; dose - response curves. Nevertheless, the following conclusions are reasonably firm:

1. Inhalation, not ingestion, will be the most important route of intake of actinides from routine releases.

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2. The risk from a few "hot particles" in the lung appears to be lower than that from the same amount of radioactivity uniformly distributed.

3. The risk of cancer induction from the actinides is judged to exceed the risk of genetic damage.

4. Routine releases of alpha-emitters and accidental releases (based on best estimates of accident frequencies) would produce risks lower than from generation of electricity from fossil fuels.

It is unfortunate that the public imagination has been captured by the so-called "horrors" of plutonium toxicity. Plutonium can, as any radioactive alpha-emitter, cause cancer and must be controlled. If it gets into the blood or lungs even a small quantity may result in malignancies after a sufficient induction period. But contrary to popular conception, large amounts can be swallowed or have contact with the skin without harmful effects; this is because of poor absorption into the body. In actuality, plutonium is no more harmful than many other substances that man deals with. Some sense of public confidence should be forthcoming from the great amount of scientific work that has been done on plutonium as referenced in the Environmental Statement. Particularly in regard to the recent postulation about extreme high risk from "hot particles" deposited in lung, it should be noted that several official bodies both in the United Kingdom and the United States have gone on record as opposing this view and supporting the validity of existing concepts.

Finally, it should be emphasized that the key issue is not the harm that will result from the LMFBR or any other fuel system; but rather, which available fuel system produces the least amount of harm and how does that amount of harm compare with the effects of having an inadequate supply of electricity.

Because of the vast amount of detail contained in the Environmental Statement itself and in the responses of the staff to comments, I have not thought it worthwhile to repeat discussions of specific details. I hope the above judgmental assessment will help serve the purposes of ERDA in fulfilling its societal responsibilities.

Very truly yours,

Cyril Comar

Cyril L. Comar, Director
Environmental Assessment Department

CLC:bhs