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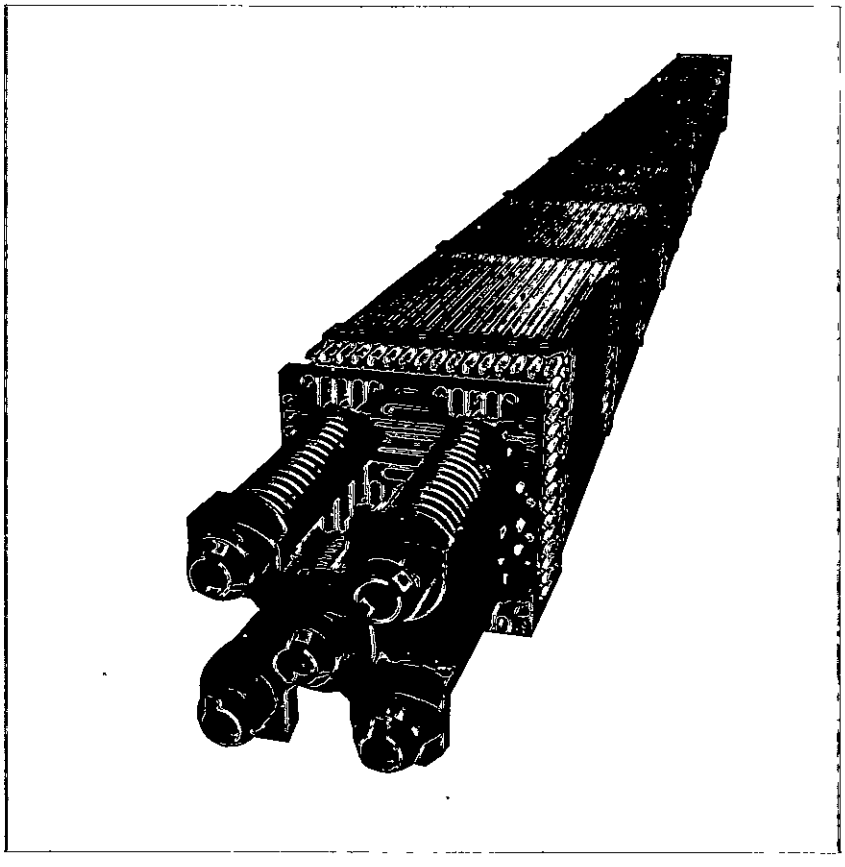
An Analysis of the Back End of the Nuclear Fuel Cycle With Emphasis on High-Level Waste Management



Prepared for

The Office of Science and Technology Policy

by

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91103

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COVER: Perspective view of a single pressurized water reactor fuel assembly containing 264 fuel rods. The core of a 1000-megawatt nuclear reactor contains about 190 of these fuel assemblies.

JPL PUBLICATION 77-59, VOLUME I

An Analysis of the Back End of the Nuclear Fuel Cycle With Emphasis on High-Level Waste Management

Thomas D. English
Project Manager

August 12, 1977

Prepared for
The Office of Science and
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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California 91103

This work was performed by the Jet Propulsion Laboratory, California Institute of Technology, under NASA Contract NAS7-100 for the Office of Science and Technology Policy (OSTP).

Foreword

This report—An Analysis of the Back End of the Nuclear Fuel Cycle with Emphasis on High-Level Waste Management—summarizes the results of a research project conducted by the Jet Propulsion Laboratory for the Office of Science and Technology Policy (OSTP).

The broad purpose of the project is to provide analytical support to OSTP in connection with the Federal Coordination Council of Science Engineering and Technology in the area of high-level nuclear waste management. The specific objectives of this project are to:

(1) Examine the most active nuclear waste disposal programs and plans to determine strengths and inconsistencies.

(2) Assess implications of schedules for waste disposal.

(3) Identify necessary but missing elements in waste disposal plans.

This study has been performed by a group drawn from the Jet Propulsion Laboratory, the campus of the California Institute of Technology, and the Scripps Institution of Oceanography. The leader of the team is Thomas English; others principally concerned with the analysis and writing the report include Edward Bullard, Lester Lees, Robert Campbell, Alan Chockie, Calvin Davis, Edward Divita, Edward Edelson, Thomas Kuehn, Joseph Klimberg, Charles Miller and Michael Ziman. The duration of the study was approximately 7 months, and involved 2 man-years of effort.

The work was funded under a National Science Foundation Interagency Agreement No. NSF-CA76-8446. The contract Technical Directors were Dr. Russell Drew, Assistant Director, OSTP and Dr. Joel Snow, Senior Policy Analyst, OSTP.

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We appreciate the assistance of the Jet Propulsion Laboratory/Cal Tech campus, Nuclear Waste Management Review Board in reviewing this report. In addition, we are thankful for the patience and skill of our secretary, Jeanne Wadsworth.

Definition of Abbreviations

ACDA	Arms Control and Disarmament Agency
ACRS	Advisory Committee on Reactor Safety
AEC	Atomic Energy Commission
AGNS	Allied General Nuclear Services
ALARA	As Low As Reasonably Achievable
ANL	Argonne National Laboratory
APS	American Physical Society
ARHCO	Atlantic Richfield Hanford Company
AWMP	Air and Waste Management Programs
CERCDC	California Energy Resources Conservation and Development Commission
CEQ	Council on Environmental Quality
CIT	California Institute of Technology
ECT	Environmental Control Technology
EIS	Environmental Impact Statement
EPA	Environmental Protection Agency
EPRI	Electric Power Research Institute
ERAMS	Environmental Radiation Ambient Monitoring System
ERDA	Energy Research and Development Administration
ESTF	Earth Science Task Force
FBR	Fast Breeder Reactor
FRP	Fuel Reprocessing Plants
GAO	Government Accounting Office
GEIS	Generic Environmental Impact Statement
GESMO	Generic Environmental Statement on Mixed-Oxide Fuels
HEDL	Hanford Engineering Development Laboratory
HLW	High-Level Wastes
HTGR	High Temperature Gas Reactor
IAEA	International Atomic Energy Agency
ICPP	Idaho Chemical Processing Plant
IE	Office of Inspection and Enforcement, NRC
ILW	Intermediate Level Waste
INEL	Idaho National Engineering Laboratory
LASL	Los Alamos Scientific Laboratories
LLL	Lawrence Livermore Laboratories

LLW	Low-Level Wastes
LMFBR	Liquid Metal Fast Breeder Reactor
LWBR	Light Water Breeder Reactor
LWR	Light Water Reactor
MIT	Massachusetts Institute of Technology
NAS	National Academy of Science
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NFS	Nuclear Fuel Services
NMSS	Office of Nuclear Material Safety and Safeguards, NRC
NPDES	National Pollutant Discharge Elimination Systems
NRC	Nuclear Regulatory Commission
NRDC	National Resources Defense Council
NRDS	Nuclear Rocket Development Station
NRR	Office of Nuclear Reactor Regulation, NRC
NWM	Nuclear Waste Management
NWTS	Nuclear Waste Terminal Storage Program
OMB	Office of Management and Budget
ORNL	Oak Ridge National Laboratories
ORP	Office of Radiation Programs, EPA
OSTP	Office of Science and Technology Policy
OTA	Office of Technology Assessment
OWI	Office of Waste Isolation
PNE	Peaceful Nuclear Explosions
PNL	Battelle Pacific Northwest Laboratory
R&D	Research and Development
RES	Office of Nuclear Regulation Research, NRC
RSSF	Recoverable Surface Storage Facility
SD	Office of Standards Development, NRC
SGR	Self-Generated Recycle
SIO	Scripps Institution of Oceanography
SRE	Sodium Reactor Experiment
TAD	Technology Assessment Division, EPA, or Technical Alternatives Document
TRU	Transuranic
UFC	Uranium Fuel Cycle

USGS	United States Geological Service
WBS	Work Breakdown Structure
WIPP	Waste Isolation Pilot Plant

Abstract

The programs and plans of the U.S. Government for the "back end of the nuclear fuel cycle" were examined to determine if there were any significant technological or regulatory gaps and inconsistencies. Particular emphasis was placed on analysis of high-level nuclear waste management plans, since the permanent disposal of radioactive waste has emerged as a major factor in the public acceptance of nuclear power. The implications of various light water reactor fuel cycle options were examined including: throwaway, stowaway, uranium recycle, and plutonium plus uranium recycle.

The results of this study indicate that the U.S. program for high-level waste management has significant gaps and inconsistencies. Areas of greatest concern include: the adequacy of the scientific data base for geological disposal; programs for the disposal of spent fuel rods; interagency coordination; and uncertainties in NRC regulatory requirements for disposal of both commercial and military high-level waste.

It is self-evident that, during the growth process, the same challenge is never presented more than once. For, ex hypothesi, so long as growth is being maintained, each successive challenge is being successfully met, or, in other words disposed of as a living issue and relegated to the history books. By contrast we can see that, in a series in which the outcome of each successive challenge is not victory but defeat, the unanswered challenge can never be disposed of and is therefore bound to present itself again and again until it receives some overdue and imperfect answer, or else brings about the destruction of a society which has shown itself inveterately incapable of responding to it effectively.

Arnold Toynbee
A Study of History

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Summary

The disposal of radioactive materials produced by nuclear reactors has emerged as a major factor in the public acceptance of nuclear power. The problems of waste disposal cannot be considered in isolation. They are intimately connected with the nature of the fuel cycle as a whole, and in particular with the decision as to whether spent fuel rods are to be reprocessed, stowed-away for possible future reprocessing, or thrown-away irretrievably.

Section I of this report describes the nature of the nuclear spent fuel recycle and waste disposal issues, in addition to the implications of various light water reactor fuel cycle options. Section II describes the complex inter-relationship of Federal, State and private sector decisions on the viability of commercial reprocessing. The economic and resource implications of various decision paths are also discussed. In Section III, the programs of the Federal Government for disposal of high-level waste from commercial reactors are examined in order to determine regulatory and technological gaps and inconsistencies. Section IV discusses the influence of Federal, State and municipal regulatory action on waste management. In addition, the results of an examination of the regulatory requirements for military and commercial high level waste management are presented. Section V brings together our conclusions. The principal function of the appendixes, contained in Volume II, is to describe the present reprocessing and waste management programs of EPA, ERDA and NRC.

To summarize our findings, it appears to us that the following matters are important:

(1) *Spent Fuel Rods*

The accumulation of spent fuel rods at reactor sites should be limited, since a continuation of present practices into the indefinite future would constitute a de facto form of nuclear waste disposal. Analysis should be carried out and plans should be formulated for the development of both centralized spent fuel pools, and centralized passive spent fuel storage facilities in order to make the "stow-away option" a viable alternative. In addition, methods and schedules for the ultimate disposal of spent fuel rods need to be developed in order to make the "throwaway option" a real alternative.

(2) *Federal Program*

The resources devoted to high-level waste management by NRC and EPA have been inadequate in view of the critical roles these agencies play in developing standards, criteria and regulations. The budgets of these two agencies have recently been increased substantially. However, we question whether the resources available to these two agencies are commensurate with their responsibilities. There appears to be a lack of an adequate platform for systematic discussion of the sufficiency of the scientific data base for geologic disposal. An important outcome of such discussion would be the development of decisions as to what parameters should be monitored, and for how long, during the test phase of a specific repository site. In addition, there appears to be a need for improved coordination of the nation's high-level nuclear waste program. One method of providing better coordination would involve formation of a high level inter-agency committee for nuclear waste management. This committee could provide a mechanism for resolving issues, and could fulfill the function of coordinating the activities of the Federal agencies concerned with nuclear waste processing, packaging, transport, and disposal. Another approach might be to appoint a

single individual from, for example, the Executive Office of the President, to serve as a focal point for the nation's high-level nuclear waste management program.

In light of President Carter's decision to defer reprocessing indefinitely, the schedule for operation of a repository for commercial high-level waste by 1985 should be re-examined and revised. In addition, the timing of the promulgation of NRC siting criteria for high-level waste disposal sites, and the site selection activities of ERDA should be revised to make them compatible.

(3) *Regulations*

NRC is mandated to license both commercial and military high-level waste repositories. NRC has not decided whether to require either site selection review and/or construction licenses for these repositories. We believe that assumption of these responsibilities by NRC could hasten the ultimate development of these repositories. In the area of pilot plant retrievable repositories for high-level waste, NRC plans to license commercial but not military pilot plants. Extending NRC's licensing authority to include military pilot plant repositories would eliminate this inconsistency.

(4) *Alternative Fuel Cycles*

Alternative fuel cycles should be systematically studied from the standpoint of reducing the problems associated with waste disposal, proliferation and safeguards.

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Section I

Introduction

A critical issue for the future development of commercial nuclear power in the U.S. is the disposition of the spent fuel from light-water nuclear reactors. This spent fuel contains highly radioactive fission products, isotopes of plutonium, uranium, and other actinides. Although the fission products in the spent fuel will have decayed to insignificant amounts after about 1,000 years, the plutonium and other actinides remain a radiological hazard for periods of 100,000 to 1 million years (Ref. 1). At present, spent fuel is accumulating at the rate of 1,400 metric tons per year. The radioactivity accompanying this annual discharge is about 6×10^9 Curies (Ci) after 160 days of cooling. Since no reprocessing plants for commercial nuclear power plant spent fuel are operating in the U.S., spent fuel rods are being stored in spent fuel pools which are primarily located at reactor sites. Even by the most conservative estimates of the growth in nuclear electrical generating capacity, the yearly discharge of spent fuel will have doubled by 1983, and the cumulative "backlog" will be about 13,000 tons. Allowing for decay, the radioactivity of this material, about 10^{10} Ci, will be approximately equal to that of all the military high-level nuclear waste ("ERDA waste") now in storage (about 400,000 tons) (Ref. 2).

A. Study Environment

Decisions concerning the disposition of spent fuel rods must be made within the framework set by Presidential policy statements. On October 28, 1976, former President Gerald Ford concluded that "the U.S. will not proceed with reprocessing and recycling of plutonium unless there is sound reason to determine that the world community can effectively overcome the associated risks of proliferation." In his energy message of April 7, 1977, President Carter announced his decisions to indefinitely defer reprocessing of spent fuel and recycling of plutonium, and to defer the development of the plutonium fast breeder reactor (LMFBR). With these statements in mind, the purposes of this report are to examine: (1) the range of policy options now open for the disposition of spent fuel rods, including advantages and disadvantages of each option; (2) the impact of each of these policy options on the Federal high-level waste management program; (3) the management of already existing military waste; (4) high-level nuclear waste and spent fuel rod management, with particular emphasis on interagency coordination, Federal, State and private sector decisions, program consistency, logic of time sequences, and gaps in present programs.

B. Principal Options

The principal spent fuel management options are throwaway, stowaway and recycle of fissile materials. These options are discussed in the following sections.

1. Throwaway Option

Since the "throwaway option" is now a distinct possibility, the spent fuel rods themselves may become the radioactive waste product, and present nuclear waste management plans would have to be revised to provide for safe terminal disposal of these fuel rods. A "throwaway" decision would mean that the "lifetime" of the LWR as an energy source would be about 10,000 GW(e)-years, corresponding to an average capacity of 200,000 MW(e) for 50 years, with a peak capacity of about 280,000 MW(e) in the year 2000. These estimates are based on a conservative prediction of U.S. reserves at 2×10^6 tons of U_3O_8. A "throwaway" decision would also mean that the option of developing the plutonium fast breeder reactor would be deferred indefinitely. However, if the throwaway

option is chosen, it might still be possible to extract sufficient ^{235}U from U.S. uranium ores to start up the non-breeder thorium light water reactor on a commercial scale in 10–15 years (Ref. 3). By recycling ^{233}U, it would then be possible to convert the conventional LWR into a ^{232}Th-^{233}U breeder reactor (Ref. 4). On the positive side, the throwaway option means that the plutonium in the spent fuel is never separated from the fission products, thus avoiding the problems of safeguards and proliferation associated with reprocessing and recycling. Radioactive gases such as ^{85}Kr, ^{3}H and ^{14}C, which would be released to the environment, are contained within the spent fuel rods. Furthermore, shipments of radioactive materials are minimized.

2. Stowaway Options

In view of present uncertainties, it seems desirable to leave open as many decision paths as possible. One such option, providing considerable flexibility, is the "stowaway" option. This involves retrievable storage and safe containment of the spent fuel rods in adequately guarded surface or sub-surface facilities, for a period of about 20 years * During this period, additional R&D (including demonstration) on permanent high-level waste disposal could be vigorously pursued in an orderly manner. Recycle options, such as "co-processing" of uranium and plutonium and the thorium light-water breeder reactor, could be thoroughly investigated. In fact, "stowaway" has many important positive features even if it is eventually decided to reprocess spent fuel. For example, after 20 years of spent fuel storage, both ^{131}I and ^{242}Cm (the transuranic nuclide with the highest specific radioactivity) would have virtually disappeared from the spent fuel. The rate of thermal energy output from the spent fuel would be reduced by a factor of about 20, compared to its value one year after discharge. On the negative side, the stowaway option involves the costs of maintaining and safeguarding retrievable storage facilities, significantly increased land use (if surface storage is selected), the possibility of cladding corrosion, and potentially increased exposure to radioactivity.

3. Recycling Options

The reason for keeping the reprocessing and recycling option open via "stowaway' is that the spent fuel from commercial light-water reactors (LWR) contains significant quantities of recoverable plutonium and ^{235}U fuel. By separating 99.5% of the U and Pu from the fission products, and recycling this reclaimed fuel in LWR's, the amount of fresh uranium U_3O_8 required to generate a given amount of electrical energy can be reduced by 30% to 40% (Ref. 5). Recycling 99.5% of the uranium reduces the mass of spent fuel materials in the high-level waste stream by a factor of 25 compared to the original mass of the spent fuel. However, since the current concept of high-level waste disposal includes placement of the cladding hulls in the same repository as the high-level waste, the net effect of recycling is to reduce the mass by only a factor of 4.

During the first decade after discharge from a commercial nuclear reactor, there is no significant difference between the recycling and throwaway options in the total radioactivity of the materials to be deposited in the high-level waste repository. However, after about 1,000 years, the radioactivity of reprocessed waste is reduced by a factor of about 10 compared with what would remain from a throwaway LWR fuel cycle. The amounts and total radioactivity of the actinides in the repository are dependent on the amount of plutonium recycled back to the reactor. This point is discussed in more detail in Appendix G.

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*This option should be carefully distinguished from the option proposed a few years ago for a recoverable surface storage facility (RSSF) for high-level nuclear waste *after* reprocessing.

Many other recycling options are available, all of which affect the character of the final "waste." For example, plutonium could be separated from the reprocessing of spent fuel and kept in storage for later utilization. The plutonium could be used in burner and breeder LWR's, or for start-up of a fast breeder reactor if a decision is made later to develop the Fast Breeder Reactor (FBR). Use of the FBR makes available about 50 times as much uranium for electrical energy generation as the open-cycle LWR. However, this potential benefit is not without risks, since these policy options raise important questions about safeguards against terrorist activity and theft of plutonium. They also account for the current interest in developing international agreements and controls on reprocessing spent fuel to prevent the proliferation of nuclear weapons.

Because of the magnitude and complexity of the problem of nuclear waste management, the Office of Science and Technology Policy requested that we concentrate our efforts on the most pressing issues affecting the current Federal high-level waste management programs for LWR's with throwaway, stowaway and reprocessing-recycling options. Particular emphasis has been placed on identifying the problems of interagency coordination; Federal, State and private sector decisions required; program consistency, logic of time sequences, and gaps in present programs. An analysis of the implications of alternative fuel cycles is recommended for a later study.

Section II

Commercial Fuel Reprocessing

A. General Considerations

The future of reprocessing of spent fuel from commercial LWR's, in the United States, will be determined as much by foreign policy considerations, institutional decisions, and capital investment decisions, as by technological and energy resource considerations. Figure 2-1 illustrates both the major decision paths that could be examined in considering nuclear fuel recycle options, and also the implications of each path for the management of spent fuel rods and high-level nuclear waste. Current U.S. policy, as defined by President Carter on April 7, 1977, is indicated by both the thick pathways and the heavily outlined boxes on the left-hand side of Figure 2-1. This policy indefinitely defers reprocessing of spent fuel rods from commercial nuclear electrical power reactors. If, at some future date, satisfactory international controls against proliferation of nuclear weapons, and satisfactory safeguards against potential terrorist activities are developed, the President might decide to proceed with reprocessing and recycling. The decision paths that would be opened up by this major policy change are indicated in the shaded half of Figure 2-1 on the right side of the figure. These paths are examined in the following sections.

1. Federal Decisions

For example, if the President decides to permit recycling of uranium without recycling plutonium, the decision path begins with the arrow labeled "yes" emerging from the decision box labeled "President Carter's U Recycling Decision" (center-left). First, the industry would determine if the economics of uranium recycle appeared to be acceptable. If the economics were favorable, and if an NRC license for private recovery of uranium were successfully obtained, then Federal decisions concerning Pu storage would have to be made. The plutonium could be stored in either an ERDA facility, or a private facility for possible later use in either potential fast breeder reactors or light water reactors. If neither of these options are chosen, the plutonium could be discarded with the high-level waste. These decisions could significantly impact the economics of the initial analysis of uranium recycling by the industry. If a re-analysis of the economics indicates that uranium recycle alone is not profitable, several options are available. The utilities could store the spent fuel rods as a potential source of future fuel. If the utilities choose not to do this, the government could choose this option. Both of these storage options are a form of stowaway. If decisions are made against both of these storage options, then the spent fuel rods themselves must be packaged and ultimately disposed of in a repository.

Even if, at some future time, reprocessing should become politically acceptable, Federal court decisions, and NRC hearings and regulations on the use of mixed-oxide (MOX) fuels, could contribute to a final decision on reprocessing. The outcome of the NRC hearings on the Generic Environmental Statement on Mixed-Oxide Fuels (GESMO, shown in Figure 2-1) concerning the health, safety and environmental aspects of plutonium recycling could be of importance in the decision-making process. In addition, NRC is scheduled to issue a safeguards supplement to GESMO in the near future, and may wish to revise the proposed rules relating to MOX fuels in the LWR cycle that are published in 41 Fed. Reg. 40506-10, December 20, 1976.

Figure 2-1 indicates that the Environmental Protection Agency (EPA) plays an important role in influencing nuclear spent fuel options. Recently, the EPA promulgated fuel cycle environmental standards (Ref. 6) that apply to ". . . most operations within the fuel cycle, including the operations of milling, conversion, enrichment, fuel fabrication,

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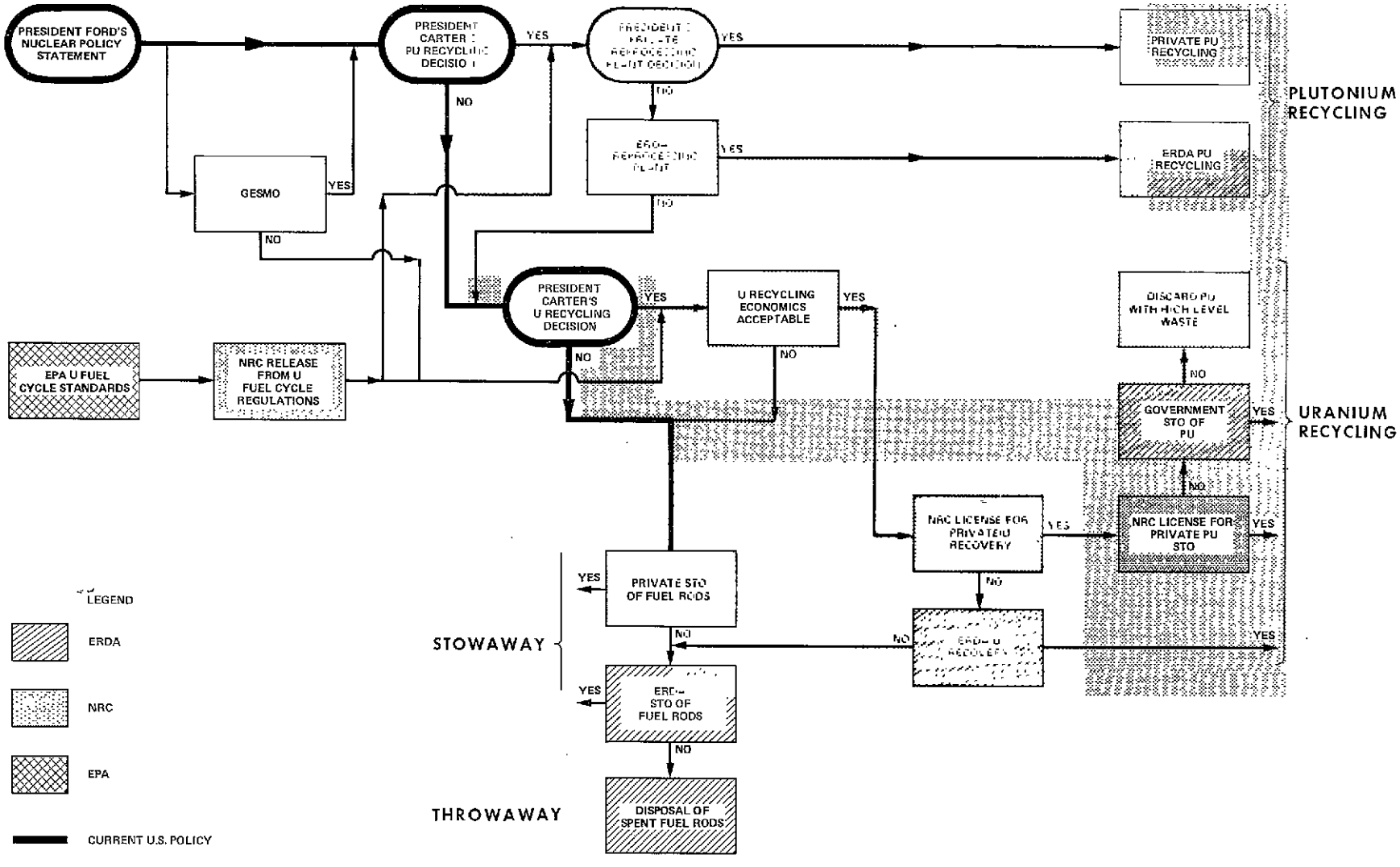

Figure 2-1. Nuclear Spent Fuel Options

light-water cooled reactors, and fuel reprocessing, but exclude mining, the transportation of radioactive materials in connection with any of these operations, and waste management operation." These standards are summarized as follows:

(1) A nearest resident shall not be exposed to more than 25 mrem/year

(2) Emissions of certain long-lived effluents shall be limited to:

- Kr-85 50,000 curies/GW(e)-year
- I-129 5 millicuries/GW(e)-year
- Actinides 0.5 millicuries/GW(e)-year

No significant technological difficulties are expected to arise in meeting these new EPA requirements; for example, the technology for cryogenic removal of Kr-85 has already been "cold-tested."

2. State and Private Sector Decisions

The impact of possible actions by individual states on reprocessing decisions is well illustrated by the hearings conducted in the Spring of 1977 by the California State Energy, Resources, Conservation and Development Commission (ERCDC) in connection with Assembly Bill #2820 (Ref. 7). This bill, passed by the State legislature in 1976, provides that *no new nuclear power plants* which require reprocessing will be granted land use by the State of California unless both the existence of a reprocessing technology, and its approval by the Federal Government are established. These ERCDC hearings have brought out the following important information concerning the status of commercial reprocessing:

(1) Facilities for the separation of U and Pu from spent fuel rods from commercial LWR's, and for the subsequent conversion of the uranyl nitrate to uranium hexafluoride have been built in Barnwell, S.C. These facilities have not been operated. Both plutonium oxide conversion and high-level waste solidification facilities have not yet been built for commercial spent fuel.

(2) Lessons learned from the now-defunct fuel reprocessing plants of General Electric at Morris, Illinois, and Nuclear Fuel Services (NFS) at West Valley, New York, led to significant design changes in the Allied General Nuclear Services' (AGNS) FRP complex at Barnwell, South Carolina (Refs. 8 and 9). AGNS management expects that these changes will overcome difficulties experienced in early U.S. FRP's.

(3) The position taken by AGNS is that the Barnwell plant should be converted to a demonstration FRP, even though $250 million has already been invested in the separations and UF_6 facility. AGNS proposes (Ref. 10) that ERDA first buy the present facility from AGNS, and then proceed to build facilities for conversion of plutonium nitrate to plutonium oxide, and also for solidification of high-level waste. Under this proposal the entire complex would be federally owned but privately operated by AGNS. In addition, AGNS proposes to reserve the right to "buy-back" the entire facility at some future date.

The above summary indicates that there is considerable uncertainty, and hence, economic risk in commercial reprocessing. Until these interrelated Federal, State and private sector questions are resolved, commercial reprocessing in the U.S. may continue to be deferred indefinitely.

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B. Economics and Resources

Estimates of the net economic benefits (or cost) of reprocessing spent fuel from LWR's are sensitive to both the predicted price behavior of Pu and U_3O_8, and to the predicted costs of storage, transportation, reprocessing and waste disposal. Whether there is a net economic gain or loss is of vital importance to the future of the commercial reprocessing industry. However, the impact of the net benefit (or cost) of reprocessing on the entire LWR nuclear fuel cycle is small. For example, the maximum net estimated benefit is on the order to 1 mill/kWh(e) in 1976 dollars, or about 6% in comparison with the estimated cost of generating electricity of about 15 mills/kWh(3) (Ref. 11). In addition, it should be noted that a capital investment of about 1 billion dollars in an FRP complex represents about 2% of the capital investment in the 50 LWR's serviced by this FRP.

Estimates of the savings in uranium (U_3O_8) resource requirements depend on: (1) the degree of enrichment of the fuel supplied to the LWR; (2) the ^{235}U content of the depleted uranium discharged from the isotope separation plant after the enrichment process, and (3) the blend of natural uranium and recycled plutonium (PuO_2) supplied to the LWR in the "equilibrium state" which is reached after 4 or 5 cycles. For example, if one-third of the reactor fuel is natural uranium blended with recycled plutonium, and the other two-thirds consists of uranium (UO_2) enriched to 3.3%, the fresh U_3O_8 requirement is about 110 tonnes per year for a 1,000 MW(e) reactor operating at 80% of capacity (Ref. 12). This figure of 110 tonnes/yr should be compared with the requirement of about 180 tonnes/year of U_3O_8 for an open-cycle LWR generating the same amount of electrical energy. Hence, a reduction of about 40% in uranium mining requirements over the lifetime of each reactor could be achieved through recycling.

If plutonium FBR's were to be developed, a certain number of LWR's would be required to devote their plutonium output to supplying the start-up loadings of the first-generation breeders. Approximately 18 GW(e)-years inventory of spent fuel from U-fueled LWR's would be required to supply the 3,100 Kg of Pu needed to start-up each GW(e) FBR (Ref. 13). Thus, if the throwaway option for spent fuel rods were adopted, there would be no viable future option of utilizing Pu-based FBR's by the U.S.

The current methods of storing spent fuel rods from commercial power reactors consist of either storage at the spent fuel pool at the reactor site, or shipment to a centralized spent fuel pool at Morris, Illinois. In either case, this form of stowaway option has economic costs associated with it that are borne by the utilities. Ultimately, these costs must be reflected in the price of electricity.

If the assumption is made that the nominal storage costs at the Morris, Illinois spent fuel pool are reflective of reactor spent fuel pool storage costs, then a rental fee of $10,000 per metric ton of spent fuel per year can be used. Since a gigawatt electrical reactor produces approximately 33 metric tons of spent fuel per year, the cost of storing spent fuel from the reactor would be $330,000 for the first year of storage. If delays in the waste disposal program cause, for example, a single year's output of spent fuel to remain in a spent fuel pool for ten years, then the cumulative storage cost for that quantity would be $3,300,000. If we consider that additional fuel is added to the spent fuel pool each year, the annual storage cost increases from $330,000 for the first year to $3,300,000 for the tenth year. The corresponding cumulative storage cost increases from $330,000 for the first year to $18,150,000 for the tenth year. If these storage costs are translated to mills per kilowatt hours, the cumulative cost for the first year is approximately .04 mills/kWh. For the tenth year, this cumulative cost increases significantly to 0.22 mills/kWh. The annual storage cost for the tenth year is 0.40 mills/kWh.

In order to avoid the possibility of having to shut down the reactors because of insufficient spent fuel storage capacity, some utilities are increasing their storage capacity through re-racking and expansion of their spent fuel pools at the reactor site (Ref. 14). The possibility of moving the spent fuel to storage sites away from the reactor is also being considered. It may appear in the economic interest of the utilities to store the spent fuel rods for a long period of time. A report by Allied General Nuclear Services (AGNS) (Reference 1) estimates the net worth of spent fuel rods from commercial power reactors to be approximately $260 per kilogram. This net worth includes the value of the recovered products minus the costs of waste handling, reprocessing, spent fuel transportation, and spent fuel storage for a single year. Assuming this value to be correct and ignoring effects of inflation, price fluctuations of uranium, etc., the break-even point for storage would occur at approximately 26 years. However, if the assumptions used in the AGNS analysis prove to be overly optimistic, the spent fuel could constitute a liability instead of an asset. This would be the case if present reprocessing policies were to continue indefinitely. An interesting situation could occur if a utility were to examine the current set of uncertainties regarding reprocessing, and decide to declare its spent fuel as high-level waste. If this occurred, would the government then be responsible for the annual cost associated with the storage of the spent fuel rods? Could the government disagree with the utility's position that the spent fuel rods were high-level waste? At present, the government's position on these matters is not at all clear. In any case, the present spent fuel rod situation constitutes an interesting uncertainty in the establishment of utility rates since spent fuel can be viewed as either an asset or a liability depending on the set of assumptions. As our previous analysis indicated, the present cost increment associated with spent fuel storage is a relatively small percentage of the overall cost of electrical power production. However, if the present practice of storing the spent fuel rods continues indefinitely, the cost to electrical utilities could become a significant fraction of its overall production costs.

Regardless of the future decision on reprocessing, disposal of spent fuel rods and/or reprocessed nuclear waste remains a major problem. The current national program for disposal of high-level nuclear waste is discussed in the following section.

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Section III

Commercial High-Level Waste Disposal

Since radioactive high-level wastes contain some of the most toxic materials known (Refs. 16–18), they must be isolated from the environment for many centuries. The time period that the waste must be isolated may be debatable, but ranges from approximately a thousand years to a million years (Refs. 19, 20). Since these isolation times are larger than the lifetimes of most social and political institutions, an ultimate waste disposal solution which would require institutional stability for these long periods of time lacks a certain degree of credibility (Refs. 21, 22).

Decision-making on the time scale of 30 generations to 30,000 generations is new to mankind. Unfortunately, *there is no way to avoid making decisions*, since large quantities of high-level nuclear waste from both the military weapons program and the commercial nuclear power program are extant and growing (Refs. 23, 24). The potential intergenerational, somatic and genetic effects are extremely difficult to calculate (Ref. 25), and therefore large "ignorance factors" are inherent. There are basic toxicological uncertainties in the radio-nuclide health effects data base. For example, Karl Morgan (Ref. 26) has estimated that the current plutonium standard for maximum permissible body burden needs to be decreased by at least two orders of magnitude (Ref. 27).

One method that appears to have promise for successfully disposing of high-level nuclear waste is deep geologic disposal. The current U.S. program gives prime emphasis to deep geologic disposal in bedded salt. This choice is based in part on the results of previous experimental activities involving the testing of concepts for disposal of high-level waste in bedded salt deposits in Lyons, Kansas (Refs. 28–31). Major questions of the predictability of geologic stability over these time scales exist (Ref. 32). There are large uncertainties concerning the rate and method of migration of radionuclides through both the geosphere and the biosphere (Refs. 33–35). Criteria for judgments, in the face of these uncertainties, are in need of considerable refinement (Ref. 36). Since there are currently strong disputes in the scientific community over both goals and criteria for acceptable disposal of high-level nuclear waste, it may be very difficult for EPA and NRC to establish broadly acceptable environmental standards and design criteria for high-level radioactive waste repositories. It is not possible to make definitive statements concerning technological capabilities for successfully disposing of high-level waste, if the basic goals and criteria have not been established.

One of the difficulties that contributes to disputes involving requirements for the disposal of both spent fuel and high-level nuclear waste is the apparent lack of an adequate platform for discussion of the sufficiency of the scientific data base for geologic disposal. Such a platform might, for example, concentrate on a systematic analysis of the various events that could lead to biologically significant quantities of high-level waste encountering the biosphere. A fault tree analysis approach could be used to describe the various possible events and pathways which might cause biologically significant quantities of the high-level waste to be transported from the geologic isolation site to the biosphere. The components of these event trees could be presented and debated both at public meetings and in scientific journals. This could lead to the development of a systematic framework for determination and accumulation of the required data for a successful containment of the high-level waste. The scientific community could identify technical components of each event and pathway element which have significant scientific uncertainty. Research programs could be formulated to reduce these uncertainties to levels which are considered

acceptable. Over a period of time, an approach of this kind could lead to an increased scientific consensus regarding the detailed site specific requirements for successful, long-term containment of high-level waste.

Some elements of this approach are presently in existence. Various groups of the National Academy of Sciences (Refs. 37–39), have published their views concerning disposal of high-level waste. New studies by the Lawrence Livermore Laboratories (Ref. 30), Battelle Pacific Northwest, (Ref. 41), and the American Physical Society (Ref. 42) are steps in this direction. If these starts are capitalized on to provide a better platform for scientific debate, it is expected that increased closure could be obtained within the scientific community concerning the detailed requirements of acceptable approaches for the long-term containment of high-level nuclear waste.

At present, the U.S. has no repositories for the ultimate containment of high-level waste from either the military programs or the commercial power programs. Plans have been formulated by the federal government, culminating in operation of a national repository for high-level nuclear waste in a retrievable mode by 1985 (Ref. 43). In order to meet this objective, a series of milestones must be met for both technological and regulatory programs. The major features of these program plans are described in the following sections.

A. Agency Activities in High-Level Waste Disposal

The principal Federal interactions between EPA, ERDA, and NRC required to develop an operating repository for commercial high-level nuclear waste are represented in Figure 3-1. In this diagram, involving 23 principal activities, EPA is involved in only one, i.e., the establishment of environmental standards for high-level radioactive waste disposition. However, the importance of this activity should not be underestimated, since the scientific defensibility of these environmental standards must be quite high in order to lead to public acceptability.

Figure 3-1 is divided into two main components of flow. The upper section indicates activities leading to the development of a repository for high-level waste. The lower section indicates the activities leading to solidification and packaging of high-level waste. If the spent fuel is declared to be waste then "packaging" refers to the packaging of spent fuel assemblies. High-level solidification, packaging and repository activities are discussed in the following section.

1. HLW Repository Activities

NRC has not decided (Ref. 44) whether to license commercial high-level waste repositories under the Code of Federal Regulations, Title 10, (Ref. 45) 10 CFR part 30 (by-product), 10 CFR part 40 (source material), 10 CFR part 50 (reactor and FRP's) or 10 CFR part 70 (special nuclear materials). NRC could also choose to develop a completely new licensing procedure for high-level nuclear waste repositories. There are compelling arguments for giving NRC maximum regulatory control. Recent experience has shown that anything less than strict regulatory control by the Federal government over HLW activities leads to court challenges by intervenors that cause costly delays in the national program of NWM (Ref. 46). The *spirit* as well as the language of the energy reorganization act also leads to the conclusion that strict regulatory control is necessary. Under licensing procedures such as 10 CFR part 50, ERDA would be required to obtain both an NRC construction permit and an NRC operating license. Furthermore, in the case of HLW repositories, it appears desirable to require an NRC site review, in order to obtain a second

independent assessment of the proposed site early in the developmental cycle. In the case of nuclear reactors, there is a precedent for site review, since an optional early site review by NRC can be requested by an electrical utility.

Since public acceptance is such a vital consideration, we believe that maximum regulatory control by NRC is essential. Therefore, we have drawn Figure 3-1 to correspond with frequent formal interaction between ERDA and NRC. The figure shows that based on EPA's environmental standard for high-level waste disposal, ERDA's generic environmental impact statement on waste management, and other information, NRC develops site selection criteria for repositories. ERDA selects sites and NRC approves sites based on these criteria. NRC develops final design and operating criteria for the HLW repositories before ERDA designs the repository. In addition, this design is submitted to NRC for a construction license. NRC must prepare a final EIS for the retrievable repository before granting ERDA a construction license. Upon approval, ERDA can start construction of a retrievable repository for commercial high-level waste. After construction, NRC could issue an operating license to ERDA to perform tests using retrievable high-level waste canisters. Subsequent to a set of repository tests which as yet have not been completely defined, NRC prepares an environmental impact statement on approval of permanent disposal of high-level waste. After this EIS is accepted, NRC can approve the permanent disposal of high-level waste at the operating site. ERDA is then in a position to accept solidified high-level waste for irretrievable disposal.

2. High-Level Waste Solidification and Packaging Activities

High-level waste solidification and/or packaging activities are shown in the lower half of Figure 3-1. These activities are applicable to either *spent fuel* or *reprocessed high-level waste*, since in the case of a throwaway decision only packaging would be required. In parallel with NRC's development of solidified waste disposal performance criteria, ERDA can finalize a demonstration program for solidification and packaging of high-level waste from light water reactors. This program would result in the design of a demonstration waste solidification facility by ERDA. Prior to the granting of a construction license, NRC must finalize an EIS for this facility. Subsequent to NRC's granting a construction license, construction activities can commence. After construction of the plant, NRC examines the facility to determine whether or not it warrants an operating license. If this license is granted, the demonstration waste solidification facility for high-level waste from light water reactors could produce waste packages suitable for shipping to the high-level waste disposal repository operated by ERDA.

According to the present federal law(Ref. 47), the Nuclear Regulatory Commission must take possession of the high-level waste at the waste repository as its "owner." This regulation appears to put NRC in a conflict-of-interest situation. It appears that ERDA should be the "owner" of the waste. This provision may have been a legislative oversight.

B. Interagency Coordination

In order to operate a repository for commercial high-level nuclear waste by 1985, a complex set of activities must be undertaken by the Federal government. An Ad Hoc Interagency Task Force on Commercial Nuclear Waste Management was formed in the spring of 1976 (Ref. 48) to insure internal compatibility of the Federal government's activities in this area. The task force was chaired by OMB and included representatives from CEQ, EPA, ERDA, NRC and USGS. This task force was phased out at the end of July 1976 (Ref. 49) and replaced by the White House Fri Committee (Ref. 50). The Fri Committee provided information for President Gerald Ford's Nuclear Policy Statement on October 28, 1976. At present, there is no interagency committee for coordinating the Federal

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government's efforts in commercial nuclear waste management, although such a group is called for in the National Energy Plan (Ref. 51).

A JPL modification of the OMB interagency task force flow chart showing the interconnection of the government's high-level waste management activities is presented in Figure 3-2. This chart shows considerably more detail than Figure 3-1, which focused principally on regulatory activities. The major milestone activities are highlighted with ellipses at the top of the chart. These major activities include providing a better definition of high-level waste; determining regulations for interim storage; preparing environmental standards for high-level waste disposal; development of general regulations by NRC; docketing of the environmental reports and applications, and construction of the repository; obtaining an operating license; and finally, receiving the high-level waste at the national repository. A similar flow chart should be prepared for spent fuel disposal.

The sub-activities which must be accomplished in order to lead to each major activity are shown below the respective major activities. Alternate sets of sub-activities have been shaded in order to make the chart easier to read. The following abbreviations have been used in Figure 3-2:

TAD	Technical Alternatives Document
DGEIS	Draft Generic Environmental Impact Statement
EIS	Environmental Impact Statement
INT	International
ENV	Environment
ACRS	Advisory Committee on Reactor Safety
DEIS	Draft Environmental Impact Statement
FEIS	Final Environmental Impact Statement
SER	Safety Evaluation Report
FSAR	Final Safety Analysis Report
FSER	Final Safety Evaluation Report.

Figure 3-2 shows that the majority of the activities occur during 1977 and 1978. In order to ascertain the credibility of the proposed schedule, and also to determine if there are major technological or regulatory gaps in the proposed schedule, it is necessary to examine the nuclear waste programs of EPA, NRC, and ERDA. A detailed examination of the available material from EPA, NRC, and ERDA is presented in appendixes B, C and D. Principal observations of the EPA, ERDA, and NRC programs are discussed in the following sections. The overall budgetary perspective shown in Figure 3-3 is quite helpful to have before considering these observations. The three "pie-charts" show the distribution of the total funds for the programmatic development of waste management technology and regulations in Fiscal Year 1975, 1976 and 1977. The dominance of ERDA's budget is clearly shown. This fact should be kept in mind when reading about the programs of these three agencies. For FY-75 and FY-76, the angles shown for EPA have been exaggerated to make them visible on the chart.

C. EPA Program Observations

The Environmental Protection Agency is responsible for the environmental radiation protection criteria and standards for nuclear waste management operations. This responsibility is implemented by the Office of Radiation Programs (ORP). An examination of the statutory authorities, programs, financial and personnel resources of ORP has revealed several apparent problem areas.

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First, environmental standards for nuclear waste management must be supported by thorough data in order to avoid unnecessary delays and costs required by future revisions of the standard. For this reason, they must be based on the best available scientific and engineering knowledge on the environmental pathways, effects of radiation, and risks to the population. The official position of the Office of Radiation Programs is that they are satisfied to leave these activities in the hands of NRC and ERDA, and that the existing scientific knowledge base is adequate for settling environmental standards. EPA will continue to use the results of ionizing radiation research being carried out by other agencies, most notably the Energy Research and Development Administration and the Nuclear Regulatory Commission, and the findings from approximately $2 billion invested in the study of ionizing radiation health effects and control technology over the past 25 years. EPA is formalizing cooperative research and operational arrangements with these agencies to assure that the technological bases for EPA standards are founded on sound scientific knowledge. However, no major cooperative research projects have been initiated by ERDA or NRC at the specific request of EPA's Office of Radiation Programs to this date.

Controversy exists over issues such as the form of the waste, whether disposal should be retrievable or irretrievable, and the determination of what constitutes an acceptable long-term hazard. Uncertainties exist regarding geologic stability, mine shaft plugging, hydrology and economics. Given the controversy, uncertainty, and complexity that characterize the present state of scientific information, the level of effort supported by the resources available to ORP appears to have been insufficient. EPA's roles and responsibilities in Nuclear Waste Management have been increasing while its financial and manpower resources devoted to these responsibilities substantially declined in recent years (see Appendix B). These trends appear to be inconsistent with increased national priorities and goals in radiation waste management. However, a recent increase (Ref. 52) in funding of $2.4 million, which is equivalent to an increase of 51% of ORP's entire program, will help to alleviate this inconsistency. Even with this increase, it appears that EPA-ORP may have considerable difficulty in meeting the present time schedules for development of environmental standards for high-level waste.

Second, research, development and monitoring of low level radiation effects, environmental transport pathways and mechanisms, and environmental and health impacts are required in order to develop, improve and verify radiation protection standards and practices. The authority and resources available to EPA for environmental ionizing radiation research and monitoring need to be strengthened and perhaps merged into a comprehensive Environmental Radiation Protection and Monitoring System.

Third, since various radionuclides present their respective hazards to environmental health regardless of their source in the nuclear fuel cycle, standards should attempt to limit the total radiation in the environment to an "acceptable level." Since the risks associated with this "acceptable level" must be balanced with offsetting benefits, it is difficult to understand how such a benefit/cost analysis can be performed to arrive at separate standards for different components and features of a complete nuclear fuel cycle. Therefore, there does not appear to be any scientific rationale for promulgating separate standards for the uranium fuel cycle, high-level waste, low-level waste, and plutonium recycle. This approach may be based on expediency because of insufficient resources.

D. ERDA Program Observations

The basic goal of ERDA's waste management and reprocessing programs is to provide safe, efficient, and timely handling and processing of spent nuclear fuel and fuel cycle waste. To achieve this goal, numerous programs and projects have been developed by

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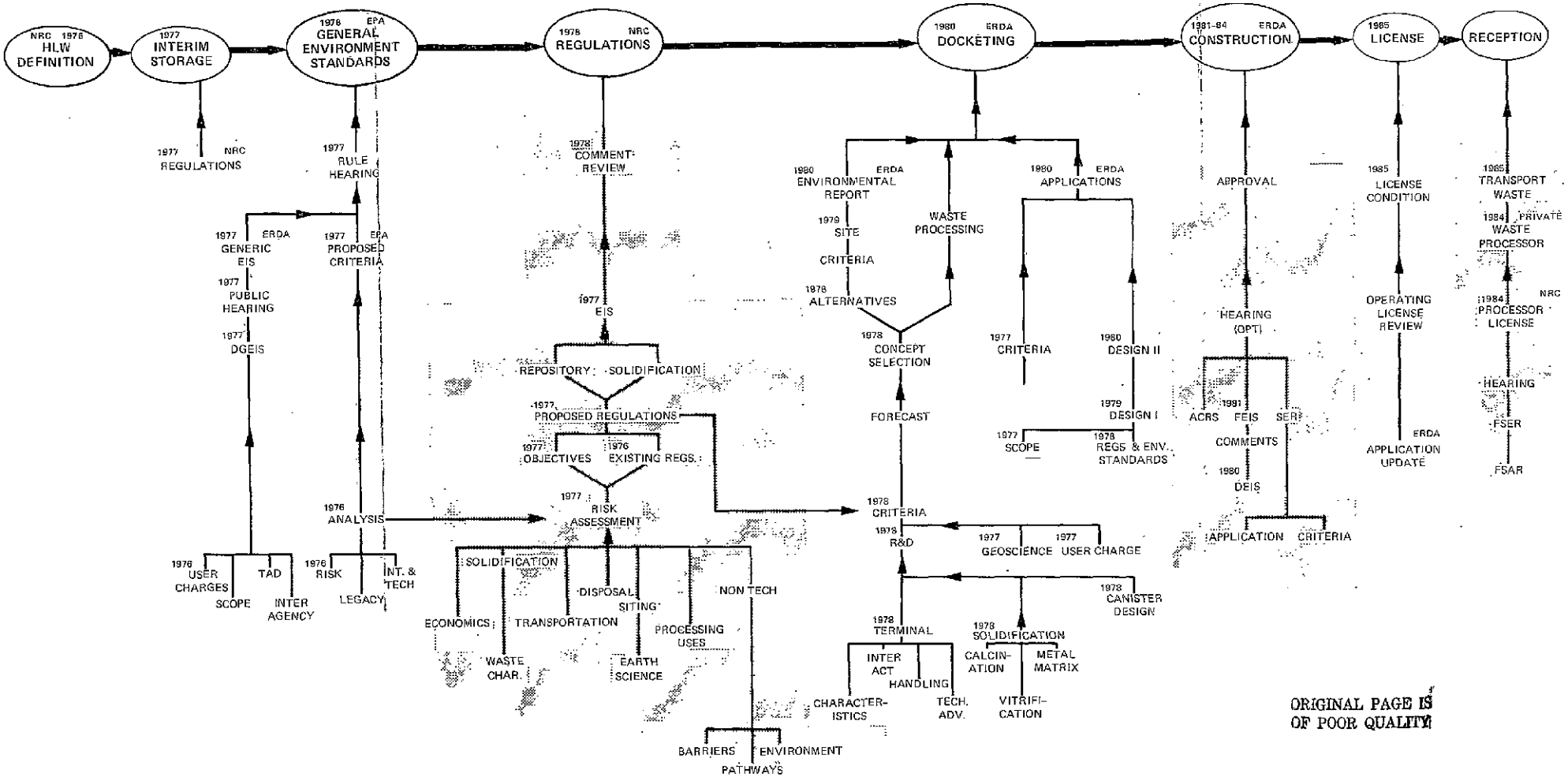

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Figure 3-2. Nuclear High-Level Waste Management Flow Chart

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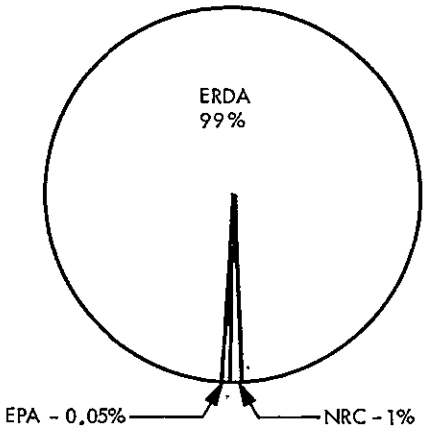
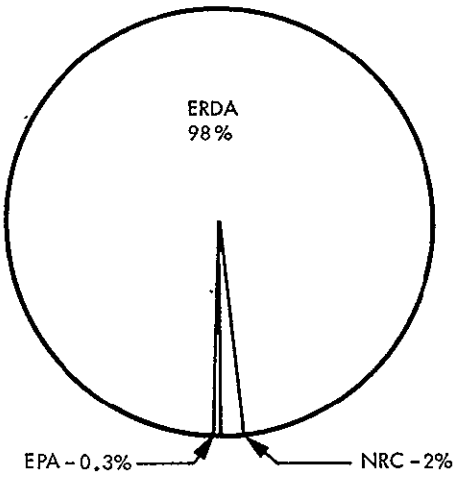
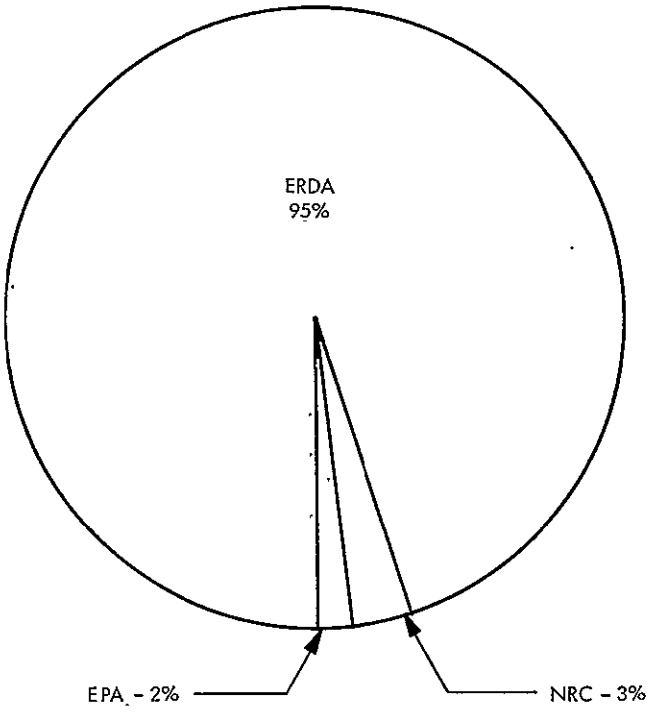


FY 1975
TOTAL BUDGET =
$65.55 MILLION



FY 1976
TOTAL BUDGET =
$85.8 MILLION



FY 1977
TOTAL BUDGET =
$176.5 MILLION

Note. Some angles exaggerated for readability.

Figure 3-3. Federal Government High-Level Waste Management Program Support (FY 1975 - FY 1977)

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ERDA. The specific objectives of a program or project are dependent on the current technological and political concern with the subject matter. A gross indication of the interest in a subject can be obtained by examining funding trends.

ERDA Program funding for waste management and reprocessing has increased 100% in FY-77 and is expected to increase by another 70% in FY-78. Significant funding increases occurred between FY-76/77 and FY-77/78 in the areas of waste management-commercial (600%, 78%), long-term waste management-ERDA (80%, 60%), nuclear fuel cycle supporting operations (over 100%/yr), and management of surplus contaminated facilities (0%, 97%). These increases should be compared with corresponding increases of 35% and 30% in the total ERDA budget. With the information available from ERDA, an analysis of the budgetary trends in combination with the program, project, and task descriptions indicated three significant areas that ERDA is not presently addressing.

(1) Until recently, there was essentially no program for disposing of unreprocessed spent fuel rods. We believe that this constituted a major gap in the ERDA program. ERDA is presently in the process of planning a relatively small program for this area (Ref. 53). In response to President Carter's statement calling for the indefinite deferral of reprocessing, there appears to be an urgent need for a considerable expansion in this program (Ref. 54). The specific aspects of this operation that are of growing concern are the long-term storage, packaging, and final disposition of the spent fuel.

(2) ERDA does not appear to be investigating the waste management implications of going ahead with reprocessing and recycling U only. Waste management operations would be affected by the inclusion of plutonium in the waste stream; also the potential hazard and the project pathways to man would be affected.

(3) Present plans for the immobilization of solidified high-level waste call for incorporating approximately 28% by weight of high-level waste in a glass (Ref. 55). A Battelle study reports information that confirms that large stresses do exist in some glasses with simulated HLW. "The RLG samples shattered into many pieces, none over 0.75 in. in their longest dimension, during core-drilling." The major criteria that lead to this percentage include leachability and reduction of packaging cost. Incorporation of this high percentage of high-level waste into a glassy cylinder a foot in diameter and ten feet long leads to centerline temperatures in excess of 650°C for one-year-old waste (Ref. 56). These high temperatures coupled with the thermal design of the package determine the center-to-center spacing of the cylinders in, for example, a proposed bedded salt repository (Ref. 57). During this study, several questions have arisen concerning the desirability of this high percentage of radioactive waste in the glass. Has a study been performed to determine the influence of HLW percentage in the glass on the net cost of the complete HLW disposal system? Lower HLW percentages in the glass would, for example, be accompanied by a decrease in radiation shielding weight for the shipping containers, and by decreased HLW cylinder centerline temperatures. Even though the number of containment holes to be drilled in the repository would be increased, the decrease in heat flux per cylinder would permit the waste cylinders to be packed in a denser array, with a possible reduction in the area of repository. A drawback to decreasing the percentage of HLW in the glass is the potential increase in radiation dose to operating personnel.

Has adequate information been obtained concerning the possibility of the incorporation of permanent stress in the glass caused by the time dependent temperature distribution within the glass? These permanent stresses could be similar to

those deliberately created in tempered glass to increase its strength. Tempered glass, however, has several drawbacks that accompany its increased strength. If a "seed" of unmelted glass feedstock is incorporated in the glass, the difference in expansion coefficient between the seed and the glass can cause the glass to spontaneously shatter years after its fabrication. This shattering can also occur if an unstable permanent stress distribution is created. If this shattering were to occur within the glass, the effective surface area of the glass would be increased by a factor of 100. Hence, geospheric transport calculations based on water leaching the surface area of a right circular cylinder could be in error by two orders of magnitude. It would be highly desirable to determine the permanent stress distribution inside the HLW glass as a function of time in order to assure that this type of shattering of the glass could not possibly occur.

E. NRC Program Observations

During the latter part of our study (March, 1977), organizational changes and significant budget and personnel revisions were initiated in the NRC waste management program. For example, the FY-1977 budget has been internally reallocated to provide for an Assistant Division Director for Waste Management with a 200% increase in contract money and a 240% increase in personnel positions. The increased emphasis is planned to continue in FY-1978.

It appears that most of NRC's research support, as shown by their contracts, comes from ERDA Laboratories (Ref. 58). This does not necessarily have an adverse affect on the operation of NRC; however, it may reduce public confidence in NRC's regulatory independence. NRC is trying to develop a more independent confirmatory research capability in the area of waste management, but has indicated that this process will take time.

One of NRC's first activities in the area of nuclear waste management program planning and development was the organization of a task force to examine the goals of waste management. In its draft reports (Ref. 59), the task force set forth three guiding principles for NRC's licensing functions:

(1) The burden of proof that the goals of a waste management system are met must rest with the proponents of the technology, and not with the opponents.

(2) Reversibility in the selection and implementation of waste management options is a virtue, and irreversibility is a flaw.

(3) Full and effective public participation must be provided at all stages of the decision-making and implementation process.

If by "reversibility" the task force means reversibility over the next few decades, we agree with this principle. However, we believe that the waste should not be indefinitely maintained in a retrievable form because of potential hazards and expenses to future generations. If these recommended guiding principles are adopted by NRC and reflected in NRC's operation decisions, it would tend to increase public confidence in the Federal program.

In later sections, the regulatory disparities between military and commercial high-level nuclear waste are discussed. Since the regulatory procedures for HLW repositories are intended to insure the health and safety of present and future generations, it is difficult to understand the basis for following different regulatory procedures for

defense and commercial HLW. We recommend that NRC have very strong and equal regulatory controls over both defense high-level waste and commercial high-level waste.

F. HLW Program Management Observations

As this section of the report has demonstrated, the national effort for disposal of high-level nuclear wastes is characterized by a complex set of institutional interactions. The principal governmental agencies involved in HLW management, i.e., EPA, ERDA, and NRC, must interact not only with each other, but also with other parts of the Federal government such as CEQ, USGS, OMB, OSTP, etc. In addition, interactions must take place between various governmental agencies, industry, state and local governments, and last but not least, the public.

The size of the HLW program for FY-78 has grown to approximately $200 million per year. This large budget is but one indicator of the importance to the society of successful management of high-level nuclear waste. Figures 3-1 and 3-2 for disposal of commercial high-level waste, provide a somewhat simplified view of the interagency activities involved in commercial high-level nuclear waste management. Considerably more detail concerning these activities is provided in Volume II, Appendixes B, C, and D, for EPA, ERDA, and NRC, respectively. As these diagrams, and the more detailed backup material in Volume II of this report indicate, the interactions between various agencies, industry, governments and public are quite complex. A highly schematic representation of the principal interactions is shown in Figure 3-4.

How can such a complex program be given more overall coherence? One possible way might be to have a central focal point for the program, that is, to "put somebody in charge." It is quite clear that an industrial group such as the Office of Waste Isolation cannot credibly be in charge of such a program, since OWI works directly for ERDA, and hence could not be held accountable for the activities of other governmental agencies. Similarly, ERDA itself cannot be in charge of this overall enterprise, since it cannot exert control over the Environmental Protection Agency and the Nuclear Regulatory Commission without violating their independence. If either the Environmental Protection Agency or the Nuclear Regulatory Commission were to be "put in charge" of this enterprise, it is difficult to understand how they could be perceived as maintaining their objectivity in regulating health and safety aspects, while simultaneously being engaged in "promotional" activities in the management of the overall program.

One possible option for providing more coherence to this program might be the formation of some interagency working group, such as the short-lived Ad Hoc Interagency Task Force on Commercial Nuclear Waste Management. In order for such a group to be effective, a clear designation of its authorities and responsibilities would be required. In addition, its "half-life" would have to be considerably longer than that of the previous interagency committee. Another possible approach to improve the HLW management program might be to appoint a single individual from, for example, the Executive Office of the President, to serve as a focal point for the nation's high-level nuclear waste management program. If either of these approaches were adopted, special care would have to be exerted to insure that the "independence" of the Nuclear Regulatory Commission was not compromised in any way, either real or perceived, by this approach.

These approaches to improvement of high-level nuclear waste management program coherence are not as sweeping as those recommended by Willrich (Ref. 60). He concludes that "the existing organization for radioactive waste management will be unworkable if left unchanged." To remedy this situation, he recommends that "a national Radioactive Waste Authority should be established as a federally chartered public corporation . . . [to]

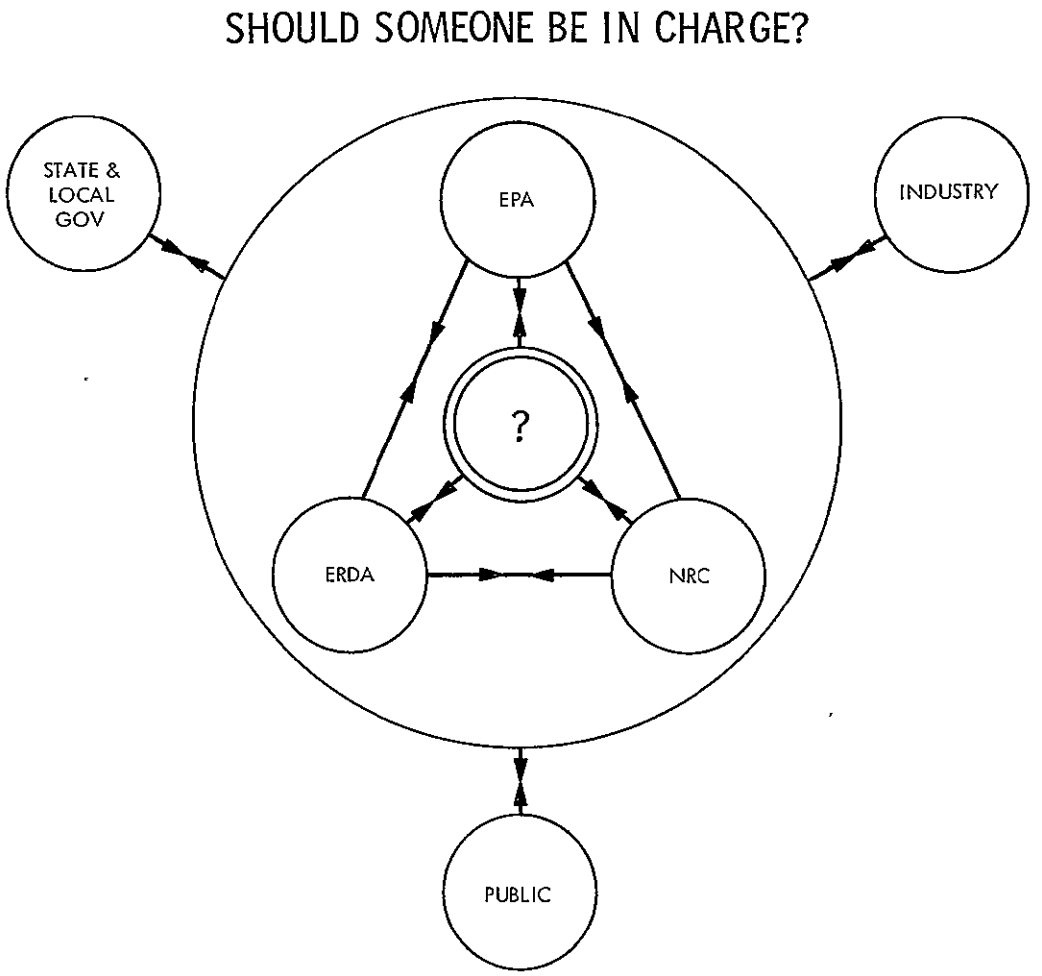

Figure 3-4. Schematic of National High-Level Waste Management Program Interactions

manage all HL and TRU wastes under U.S. jurisdiction." This approach is quite interesting; however, its adoption could be accompanied by organizational transients that would at least initially delay the program. Whether or not the initial delays associated with this plan would be adequately compensated for by subsequent significant improvements does not appear to be clear.

The options involving either a coordinating group or a single individual as a program coordinator and decision-making focal point appear much simpler to implement with minimal organization transients. Such arrangements would help to eliminate program inconsistencies, such as the conducting of repository site selection activities by ERDA before the promulgation of siting criteria by NRC. It could also be quite useful in more quickly removing uncertainties concerning requirements for site review and construction licenses for the disposal of high-level nuclear waste. The reduction of inconsistencies and uncertainties would tend to increase the public acceptability of this program.

Another action that would remove some of the uncertainty regarding high-level waste would be a better definition of the term high-level waste. A need for improved definitions of high-level waste has been pointed out by both the Environmental Protection Agency (Volume II, page B-25) and the Nuclear Regulatory Commission (Volume II, page D-18). It appears desirable that the redefinition include consideration of parameters such as the quantity of specific radionuclides, concentrations, and toxicity, and not simply be oriented toward the source of the radionuclides. Hopefully, definitions can be developed in such a manner that the disposal requirements for a given quantity of actinides are independent of whether they are contained in high-level waste or in low-level waste.

Section IV

Institutional Interactions

Having considered the range of strategic decisions available in selecting commercial nuclear fuel recycle options in Section II, and the former U.S. "mainline" program for disposal of commercial high-level nuclear waste, in Section III, we are now in a position to examine some of the principal institutional interactions affecting nuclear waste management. The importance of effective institutional interactions in the successful development of both commercial and military high-level waste repositories has been emphasized by Willrich (Ref. 61). Important factors to be considered in examining these interactions include:

- The distribution of regulatory responsibilities among federal, state and municipal organizations.
- State and local actions.
- Transportation issues.
- Timing of programmatic activities

These factors are discussed in the following sections.

A. Regulatory Responsibilities

A summary of the institutions responsible for performing specific regulatory functions for various high-level waste management processes is shown in Figure 4-1. The regulatory functions shown are: environmental guidance and standards, siting approval, construction licensing, operations licensing, and monitoring and enforcement. The waste management processes shown include: temporary storage, treatment, packaging, transportation, retrievable storage, and permanent disposition. This chart is based primarily on Willrich's legislative analysis (Ref. 62).

B. Some Regulatory Uncertainties

For the areas of both retrievable storage and permanent disposition of HLW, Figure 4-2 points out that NRC has not decided its position on the requirements for the following regulatory steps:

(1) Commercial Siting Review for retrievable storage.

(2) Commercial Siting Review for permanent disposition.

(3) Military Siting Review for retrievable storage.

(4) Military Siting Review for permanent disposition.

(5) Commercial Construction Licensing for retrievable storage.

(6) Commercial Construction Licensing for permanent storage.

(7) Military Construction Licensing for retrievable storage.

(8) Military Construction Licensing for permanent disposition.

Even though NRC has not decided on these matters, our entries shown in Figure 4-1 are based on ERDA's plans (Ref. 64) in the case of military waste, and on the assumption of a strong regulatory position in the case of commercial waste. In the case of nuclear reactors, there is a precedent for site review, since an optional early site review can be requested by

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PROCESS → / REGULATORY FUNCTION ↓	TEMPORARY STORAGE	TREATMENT	PACKAGING	TRANSPORTATION	RETRIEVABLE STORAGE	PERMANENT DISPOSITION
ENVIR. GUIDANCE AND STANDARDS	P	P	P	P	P	P
SITING REVIEWS						
COMMERCIAL	N	N	-	-	N*	N*
MILITARY	R	R	-	-	R*	R*
CONSTRUCTION LICENSING						
COMMERCIAL	N	N	-	-	N*	N*
MILITARY	R	R	-	-	R*	R*
OPERATIONS LICENSING						
COMMERCIAL	N	N	TNP	ISTMNP	N	N
MILITARY	R	R	TRP	ISTRP	N	N
MONITORING AND ENFORCEMENT						
COMMERCIAL	NP	NP	TNP	ST	NP	NP
MILITARY	R	R	TR	ST	N	N

KEY:

D = Dept. of Defense
I = Interstate Commerce Commission
N = NRC
M = Municipalities
P = EPA
R = ERDA
S = States
T = Dept. of Transportation
* = NRC has not decided on these matters

Figure 4-1. High-Level Management Process/Regulatory Function/Responsibility Matrix

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FOLDOUT FRAME 2

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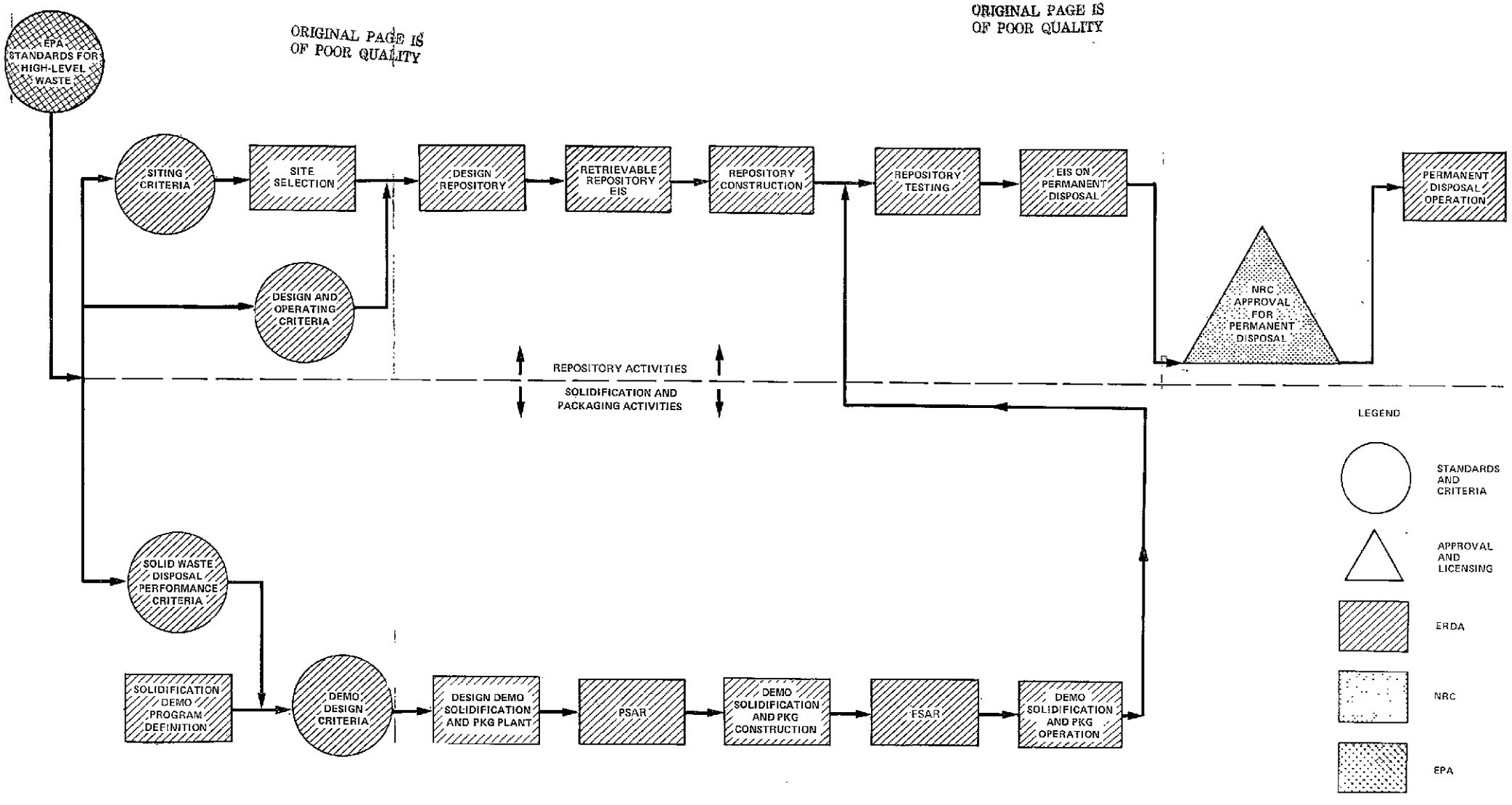

Figure 4-2. Solidification and Disposal of ERDA-Defense High-Level Nuclear Wastes

an electrical utility. A clarification of these matters by NRC would remove one component of uncertainty from the U.S. high-level waste management program.

If NRC is "excluded" from both site selection review and the granting of construction licensing, it would not be able to make important independent formal judgments of the adequacy of the repository until the application for an operating license was filed. If, at that time, NRC found the site to be inadequate, the entire process of site selection and construction would have to be repeated for a new site. This type of potential delay could be avoided if NRC exercised regulatory authority over both siting and construction. The additional efforts that these requirements would impose on ERDA do not appear to be excessive, since ERDA personnel (Ref. 65) have indicated that they plan to informally submit the same information to NRC that would be submitted if formal site review and construction licensing were required. In addition, this type of strong regulatory control by NRC could help to improve public perception of the national high-level waste management program. Hence, we conclude that NRC should have regulatory control over siting and construction of high-level waste repositories for both commercial and military waste.

1. Operations Licenses for Military HLW Management

Referring back to operations licensing entries shown in Figure 4-2, it is interesting to note that *ERDA is regulating itself in the areas of temporary storage treatment.* According to Willrich, ". . . this type of ERDA self-regulation is specifically authorized by the Atomic Energy Act of 1954. This approach may be justifiable on national security grounds in part."

The Energy Reorganization Act of 1974 provides NRC the authority to license only certain ERDA facilities:

> ". . . Retrievable surface storage facilities and other facilities authorized for the express purpose of *subsequent long-term storage of high-level radioactive waste generated by the Administration*, which are not used for or are part of, research and development activities." (Emphasis by authors)

Hence, NRC clearly must license the operation of retrievable storage and permanent disposition facilities for military high-level waste as is shown in Figure 4-1.

2. Military HLW Experimental Program

Under current regulations the Energy Research and Development Administration is permitted to conduct experimental tests of military high-level waste without obtaining an NRC operating license. In the case of the commercial high-level waste, ERDA is required to obtain an NRC license in order to conduct repository tests. This represents a different regulatory treatment for the military and commercial high-level nuclear waste. This difference can be justified in several ways.

If the site for these experiments is not intended to be the site for ultimate disposal of the high-level waste, it appears reasonable that some samples could be tested at the site for some period of time and then removed. In the Waste Isolation Pilot Plant (WIPP) program such tests are planned. An important question could be raised—"How many cylinders constitute an experimental test? Is the number 1, 10, 100, or possibly 1,000?" The Waste Isolation Pilot Plant (WIPP) program appears to consider that the deposition of hundreds of cylinders is an experimental rather than production activity (Ref 66). As a rough point of comparison, 10 cylinders of solidified high-level waste represent the HLW output of a 1,000 megawatt nuclear reactor for one year. Hence, the number of cylinders involved in the WIPP experiment would represent a substantial fraction of the HLW from U.S.

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electrical power nuclear reactors. Testing such a large number of high-level waste cylinders could be perceived as a violation of the conditions under which no license is required. This could lead to suits by intervenors which could cause serious delays in the WIPP program. One way to *avoid these potential problems would be for ERDA to apply for an NRC license for the WIPP high-level waste demonstration.* The possibility of licensing the WIPP facility has been mentioned in a WIPP report previously (Ref. 67). This approach could restrict some of the flexibility in the ERDA program, and could lead to some delays because of the necessary paperwork; however it would also tend to increase the public acceptability of these tests.

Having considered the general framework for high-level waste regulatory responsibilities, and some of the current regulatory issues, it is appropriate to examine the impact of current state and local actions on these matters.

C. State and Local Actions

The publicly acceptable resolution of the issues involving fuel reprocessing and waste disposal involves institutional interactions among federal and state governments, industry (both nuclear vendors and utilities), and the public. Under the 1954 Atomic Energy Act, the federal government has preempted the states from certain decisions in the nuclear fuel cycle. Section 274 of the 1959 amendment to the Atomic Energy Act appears to further strengthen the federal preemptory powers. The Supreme Court has upheld the rights of federal preemption in the Minnesota (Ref. 68) case, denying the right of a state to set environmental standards for a nuclear power plant that are more stringent than the standards set by the federal government. It is interesting to note that, by contrast, the states are free to set standards that are more strict than federal standards for fossil fuel power plants. Recent initiatives in states such as California on issues of waste disposal and reprocessing (Ref. 69) cause the political viability of preemption to be a cloudy issue. Furthermore, the recent letter from ERDA ex-administrator Seamans to the governor of Michigan (Ref. 70) appears to have granted the states a veto over whether or not the federal government will be allowed to put a high-level waste disposal site in a given state.

State and local governments are becoming increasingly active in nuclear fuel cycle issues. Initiatives to delay or stop the growth of nuclear power have been voted upon in California, Colorado, Arizona, Ohio, Oregon, Washington and Montana (Refs. 71-74). Although these initiatives have been defeated, they indicate that a substantial portion of the population is concerned about issues involving nuclear safety, reprocessing and waste management. In general, the lack of agreement among scientists and engineers (as evidenced, for example, by the ERCDC hearing testimony), (Refs. 75-78), concerning the adequacy of our scientific data base for high-level waste disposal decisions, is shared by large segments of the public. Public confidence in governmental plans and actions in the high-level waste disposal area is crucial to the successful development of an ultimate repository for high-level waste disposal.

D. Site Selection/Criteria Timing

The national plan for developing a permanent repository for commercial high-level waste is designed, in part, to engender public confidence in the nation's ability to properly dispose of this waste. As a part of this effort, ERDA is planning to select two nuclear high-level waste repository sites by 1978 (Refs. 79, 80). NRC is planning to propose repository suitability criteria by January 1978 and finalize the criteria by September 1978 (Ref. 81). According to R. Cunningham of NRC (Ref. 82), " . . . this is a very difficult schedule to meet . . . but we think we can do it. . . . A big unknown is how long the public hearing procedures go on. . . . That's something we can't control."

A summary of the response of Dr. Taylor, Science Advisor to the Governor of Michigan, to the above plan follows (Ref. 83).

> "The problem outlined by Dr. Kuhlman specifies the location of the first two repositories by 1978. And that is the program that's been given to us in Michigan, the program that we feel we're operating under. Yet, the technology for reprocessing, for solidification, and even for the design of the repository, is not scheduled to be completed by 1978. We've heard from Dr. Cunningham today that the criteria for sites would not be out until 1979, perhaps 1980. The design of the repository is scheduled for completion in 1982. This means that the states that are being considered are really being asked to agree to the selection of a site in their state on the promise that the activities can be operated safely.
>
> Now, even if you can convince the state government officials—the Governor, the Legislature, and Energy Commission—that the risks are small and that the problems will be solved before nuclear waste is finally reposited in 1985 or, as Mr. Shealy (Ref. 84) recommended, that we can convince a group of state officials that the problems can be solved, I don't think we're going to convince the people that the problems are going to be solved in 1978 when the site has to be selected."

It appears that the order of activities for the selection of sites and the development of site selection criteria should be reconsidered, in order to avoid needless difficulties with the states. This may require a change in the 1985 deadline for an operational High-Level Waste Repository. Since this schedule needs to be reexamined in light of President Carter's decision to indefinitely defer reprocessing, this may be an opportune time to make such adjustments to avoid needless irritation of state and local governments.

E. Transportation Issues

Several transportation issues pose problems for the management of high-level nuclear waste. The issues include:

(1) State and local government attempts to restrict or prohibit shipment.

(2) Railroads requiring special trains with speed and other operating restrictions.

Commercial spent fuel rods and research fuel rods have been transported to both the NFS facility in West Valley, New York and the GE facility at Morris, Illinois. Licensing of transportation systems and shielding casks is jointly conducted by the NRC and the Department of Transportation (DOT). A memorandum of Understanding between the Department of Transportation and the Atomic Energy Commission was published in the Federal Register in April of 1973 in order to define the division of regulatory authority between these agencies. Required specific standards and criteria (Refs. 85, 86) are based upon the International Atomic Energy Agency (IAEA) criteria published in 1967.

Increased concern over the safety of such shipments has been expressed by state and local governments, by railroads, and by organized intervenor groups. Some state and local governments have attempted to restrict or prohibit the shipment of radioactive materials through their regions (Refs. 87, 88). ERDA has challenged these actions on the basis of federal preemption of the regulations of such shipments. Lack of resolution of these cases adds uncertainty to both the cost of existing facilities, and the siting of future nuclear facilities. The American Asociation of Railroads believes that special trains are required for shipping of nuclear materials. These trains must stop when other trains pass by, and are limited to speeds of 35 miles per hour. If a train were to carry spent fuel rods, it would not be permitted to carry any other freight or passengers. The proposed tariff charges that the railroads have filed before the Interstate Commerce Commission have been protested by ERDA and the nuclear industry. ERDA and the nuclear industry have challenged the

railroads' position that they are common carriers of nuclear materials. The ICC has allowed the proposed tariff charges to go into effect pending a final decision on their propriety. "Under this new tariff, all rail shipments of nuclear spent fuel and waste must be moved only in special trains, at an additional cost of about 20 dollars per mile, or about 30,000 dollars each for an average 1,500 mile one-way trip. This increment of 30,000 dollars is to be compared with the regular freight charge of about 8,000 dollars for such a shipment (Ref. 89).

In contrast, the trucking industry appears to be enthusiastic about shipping nuclear materials. However, extensive use of trucks could lead to increased costs of unloading the spent fuel rods from the reactor spent fuel pools, since the truck spent fuel shipping casks are somewhat smaller than those for trains. In addition, the increased number of shipments could have an adverse impact on the public acceptability of these shipments. According to the ERC Nuclear Sub-Committee staff (Ref. 90): "If a combination of economic and regulatory constraints make all present transportation modes, infeasible or unacceptable, the possibility of Federal control of all shipping may have to be considered. Concern over theft or diversion of fissile materials has already led to discussion of this possibility, and the Federal government has recently taken over all shipments of nuclear materials in the Department of Defense programs."

The throwaway option has a transportation advantage if the fuel rod packaging facility is collocated with the high-level waste repository, since this approach would eliminate shipment from a reprocessing plant to the repository. The same considerations apply to collocation of the fuel reprocessing plant (FRP) and the repository; however, collocation of high-level waste repositories at current FRP sites may not be geologically desirable. According to the National Academy of Sciences Committee on Waste Disposal (Ref. 91): "No existing AEC installation which generates either high-level or intermediate-level waste appears to have a satisfactory geological location for the safe disposal of such waste products." However, a later Academy report (Ref. 92) concludes that " . . . there is a reasonable prospect of achieving such protection (for not less than 1,000 years) in vaults in rocks underlying the Tuscaloosa Formation beneath the Savannah River Plant site. This conclusion refers only to wastes that have been aged a minimum of 10 years."

In view of these different views at the National Academy of Science perhaps new "power parks" could be built at locations with suitable geologic structure (Ref. 93). "If transportation of nuclear materials becomes uneconomic due to physical or regulatory difficulties, a greater incentive will apply to investigate integrated nuclear energy centers in which fuel conversion, enrichment and fabrication as well as reprocessing and waste disposal might be provided for a complex of reactors providing from 10 to 20 GWe. The difficulties in implementing the construction and operation of such centers should not be minimized."

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Section V

Findings and Observations

In the preceding sections of this report, we have examined the most pressing issues affecting Federal high-level nuclear waste management programs. Particular emphasis has been placed on identifying the problems of interagency coordination; Federal, State, and private sector decisions required; compatibility (or its absence) between these elements in a logical time sequence, and gaps in present programs. Our principal findings and observations are outlined in this Section.

A. Disposition of Spent Fuel Rods

A Presidential decision to indefinitely defer the reprocessing of commercial spent fuel rods has been made. This decision has important implications for waste management. At present, spent fuel rods are accumulating in spent fuel pools at reactor sites that are widely distributed across the country. Over one million fuel rods per year would be discharged from a system of reactors producing 100 GW(e), so the problem of their long-term storage is far from trivial. The accumulation of spent fuel rods at reactor sites should be limited, since a continuation of present practices into the indefinite future would constitute a de facto form of nuclear waste disposal. Concentration of spent fuel rods in a few regional spent fuel pools may become economically attractive, but it does nothing to reassure the general public that the U.S. is capable of solving the problem of permanent disposal. However, if unforeseen significant delays should arise in the program to develop an operational repository by 1985, there is some risk of deterioration of fuel rod cladding in the water basin, and subsequent leakage of radioactive material. For this reason, it may be necessary to provide interim dry, passive, retrievable storage in either surface or sub-surface facilities, until acceptable permanent repositories are available.

B. Throwaway/Stowaway and Reprocessing/Recycling

Even if the spent fuel rods are transferred to centralized, Federal spent fuel pools they cannot be kept there indefinitely. If the "throwaway option" is selected, the lifetime of the LWR as an energy source would be limited to about 50 years by U.S. uranium reserves. Furthermore, the opportunity for developing the plutonium fast breeder reactor in the U.S. at some future date would be lost. On the positive side, the "throwaway option" insures that the plutonium and other radioactive substances such as ^{85}Kr, ^{3}H, and ^{14}C in the spent fuel rods are not separated from the fission products, thus minimizing the problems of environmental gaseous controls, safeguards and proliferation. Also, shipments of radioactive materials are minimized, especially if the spent fuel assembly packaging plant and the disposal site are collocated.

The "stowaway option" provides the flexibility that may be required under present and continuing uncertainties. This option involves retrievable storage and safe containment of the spent fuel rods in well-guarded surface or sub-surface Federal facilities for a period of a few decades. In another form of this option, the utilities could store the spent fuel in the hope that the net economic value of the fissile materials would exceed their costs for storage, transportation, and reprocessing. During this storage period, R&D (including demonstration) on permanent high-level waste disposal and alternative nuclear fuel cycle options could be vigorously pursued in an orderly manner. Regardless of the final decision on disposal of spent fuel rods, stowaway for a period of, for example, 20 years, has the advantage of reducing both the radioactivity and the rate of thermal energy output by a factor of 20, compared to respective values one year after discharge. On the

other hand, the stowaway option has several drawbacks compared with the throwaway option. These include increased costs of maintenance and safeguards, increased land use, and the possibility of increased exposure of the population to radioactivity.

Whether or not a satisfactory system of international controls and safeguards for commercial reprocessing and recycling of plutonium and uranium is developed, the adoption of the "stowaway option" would allow the U.S. to be in the position of being able to use the fissile material in spent fuel at some future date, if it so desires.

C. Commercial Fuel Reprocessing

By reprocessing spent fuel and recycling the recoverable plutonium and uranium, the amount of fresh uranium (U_3O_8) required to generate a given amount of electrical energy can be reduced by 30% to 40% as compared with the open-cycle LWR. In addition, after about 1,000 years, the radioactivity of reprocessed fuel waste is reduced by a factor of about 10 compared with throwaway waste from a LWR fuel cycle. Many other LWR fuel cycle options are available, all of which affect the character of the final "waste." Decision paths showing these options are discussed in Section II.

Even if reprocessing and recycling should become politically acceptable at some later date, the future of commercial fuel reprocessing in the U.S. will continue to be surrounded by uncertainties, and hence, economic risk. Some regulatory uncertainties arise out of current NRC hearings and regulations on the health, safety and environmental aspects of plutonium recycling. Other uncertainties involve the economic desirability of reprocessing. On the other hand, no significant technological uncertainties are expected to arise in meeting the new EPA standards for population exposure (25 m rem/year), and for discharge of ^{85}Kr, ^{129}I and actinides from fuel reprocessing plants.

In addition to Federal legal and regulatory actions, the States are taking an increasing interest in all aspects of reprocessing, as exemplified by the extensive hearings being conducted in 1977 by the State of California.

These hearings have brought out important information concerning the technological and capital investment problems of commercial reprocessing, and the highly probable requirement for Federal financing in the early stages.

D. Commercial High-Level Waste Disposal

Since large quantities of high-level nuclear waste from both the military weapons program and the commercial nuclear power industry are extant and growing, *there is no way to avoid making decisions that could potentially affect the lives of the next 30 to 30,000 generations.* A nuclear waste management plan has been formulated by the Federal government culminating in the operation of a national repository for high-level nuclear waste in a retrievable mode by 1985. This plan has two major components: (1) activities leading to the development of a repository, including site selection, construction, operations, monitoring and enforcement; (2) activities leading to solidification and/or packaging of high-level waste. A thorough review of the programs of EPA, ERDA and NRC (Section III) led us to the following observations and conclusions:

(1) Recent experience with Federal court challenges by intervenors, as well as the *spirit* and language of the energy reorganization act, leads to the conclusion that strict regulatory control over HLW activities is essential to gain public acceptance and avoid costly delays in the NWM program. Under Licensing Conditions such as those in 10CFR50, ERDA would be required to obtain both an NRC

construction permit, and an NRC operating license It seems highly desirable that NRC adopt this type of dual licensing requirements for commercial high-level waste repositories. In addition, it appears desirable to require an NRC disposal site review.

(2) The NWM program for commercial high-level nuclear waste involves a complex set of interactions among the various Federal agencies requiring closer coordination. The establishment of an interagency committee for coordinating all of the Federal government's efforts in commercial NWM is one way of eliminating this gap. Another approach might be to appoint a single individual from, for example, the Executive Office of the President to serve as a focal point for the nation's high-level nuclear waste management program.

(3) Given the controversy, uncertainty and complexity that characterize the present state of scientific information required for setting environmental radiation protection criteria and standards for nuclear waste management operations, the resources available to the Office of Radiation Programs (ORP) of EPA appear to have been insufficient. A recent 51% increase in funding, $2.4 million, will be of assistance to the EPA program. Even with this increase EPA-ORP may have considerable difficulty in meeting the present tight time schedule for development of environmental standards for HLW.

(4) An analysis of the ERDA program indicated three significant areas that the agency has not been adequately addressing:

   (a) Disposition of unreprocessed spent fuel rods, especially the long-term storage, packaging and final disposition of the spent fuel.

   (b) Waste management implications of a decision to proceed with U-recycling only, especially with regard to the inclusion of large amounts of plutonium in the waste stream, and the potential hazards and projected pathways to man.

   (c) Influence of the weight percentage of HLW in glass on the long-term stability of the glass.

(5) It appears that most of NRC's research support, as shown by its contracts, comes from ERDA Laboratories (Ref. 94). This does not necessarily have an adverse effect on the operation of NRC; however, it may tend to reduce public confidence in NRC's regulatory independence. NRC is trying to develop a more independent confirmatory research capability in the area of waste management but has indicated that this process will take time.

(6) In its draft reports (Ref. 95), the NRC nuclear waste management task force set forth three guiding principles for NRC's licensing functions:

   (a) The burden of proof that the goals of a waste management system are met must rest with the proponents of the technology, and not with the opponents.

   (b) Reversibility in the selection and implementation of waste management options is a virtue, and irreversibility is a flaw.

   (c) Full and effective public participation must be provided at all stages of the decision-making and implementation process.

   These principles appear sound if by "reversibility" the task force means reversibility for the next few decades but not for the long term.

(7) Given the controversy, uncertainty and complexity that characterize the present state of scientific information required for setting environmental radiation protection criteria and standards for nuclear waste management operations, the resources available to NRC for Nuclear Waste Management appear to have been insufficient. A recent increase in funding of $3.6 million, which amounts to a 150% increase, will be very helpful. Even with this increase NRC may have considerable difficulty in meeting the present tight time schedules.

E. Institutional Interactions

Effective institutional interactions are essential for the successful development of both the military and commercial high-level nuclear waste management programs. Our analysis of these interactions in Section IV led to the following observations and conclusions:

(1) NRC has not yet decided on its position on regulatory requirements for both retrievable storage of, and permanent disposition of high-level wastes in these areas: (a) commercial and military disposal siting review; (b) commercial and military disposal site construction licensing.

If NRC is "excluded" from site selection review, and granting a construction license, it would not be able to make important, independent formal judgements of the adequacy of the repository until the application for an operating license was filed. If at this time, NRC found the site to be inadequate, the entire process of site selection and construction would have to be repeated for a new site. This type of potential delay could be avoided if NRC had regulatory authority over both siting and construction. The additional efforts that these requirements would impose on ERDA do not appear to be excessive, since ERDA personnel (Ref. 96), have indicated that they plan to informally submit the same information to NRC that would be submitted if formal site review and construction licensing were required. In addition, we believe that this type of strong regulatory control could help to improve public confidence in the national high-level waste management program. Hence, we conclude that NRC should have regulatory control over both siting for, and construction of high-level waste repositories for commercial and military waste.

(2) Under current regulations, ERDA is required to obtain an NRC license to conduct pilot repository tests for commercial high-level waste; however, a similar license is not required for military high-level waste. In the proposed military Waste Isolation Pilot Plant (WIPP) program, tests of hundreds of cylinders containing high-level waste are being planned at a site which is not necessarily intended as a permanent disposal site. This disparity in licensing procedures could lead to court suits by intervenors that could cause serious delays in the WIPP program.

(3) ERDA is planning to select two high-level waste repository sites by 1978, and is already actively engaged in surveying and drilling operations. Yet, NRC's proposed repository site selection suitability criteria will not be finalized until late 1978 or early 1979. This timing inconsistency may adversely influence the acceptability of this program. It appears that the present schedule of ERDA activities for site selection should be reconsidered, even if it means a change in the 1985 target date for an operational HLW repository.

(4) Several important transportation issues pose problems for the NWM program:

(a) State and local government attempts to restrict or prohibit shipment of high-level nuclear waste.

(b) Requirement by railroads of special trains with speed, other operating restrictions, and increased costs. In contrast to the railroads, the trucking industry appears to be enthusiastic about shipping nuclear materials. However, the extensive use of trucks could lead to increased costs because of the large number of smaller casks; also the increased number of shipments could have an adverse impact on public acceptability. Concern over theft or diversion also affect this area. As a last resort the possibility of Federal control of all shipping of nuclear wastes may have to be considered.

F. Alternative Fuel Cycles

Alternative nuclear fuel cycles should be thoroughly evaluated with the objective of minimizing the problems of high-level waste disposal, proliferation of nuclear weapons, and safeguards against theft or terrorist attacks. This analysis should include not only the uranium-fueled CANDU heavy-water reactor and the LWR-CANDU tandem reactor, but also the thorium-^{233}U high temperature gas-cooled reactor (HTGR) and the ^{232}Th-^{233}U light water breeder reactor (LWBR).

The LWBR is an attractive alternative to the LWR for at least four main reasons:

(1) The radioactivity of the recycled ^{233}U and ^{235}U is about 50 times lower than the radioactivity of the recycled plutonium and uranium in the self-generated LWR (SGR) (4500 Ci per GW(e)-year vs 225,000 Ci per GW(e)-year), (Ref. 97).

(2) The difficulty in separating ^{233}U and ^{235}U acts as a barrier to potential theft or diversion of recycled fuel for the manufacture of nuclear weapons.

(3) The amount of long-lived plutonium in the high-level waste for the LWBR cycle from reprocessing is less than 4 kg per GW year, and the amounts of americium and curium are about one-tenth of this figure (Ref. 70). After storage for 1000 years the radioactivity of this reprocessed waste is about 100 times lower than the radioactivity of the spent fuel from an open-cycle LWR, and it is no greater than the radioactivity of the thorium and uranium ores from which the reactor fuel was extracted (Ref. 98).

(4) U.S. thorium reserves are about 3 time larger than U.S. uranium reserves.

G. Concluding Remarks

In the course of this analysis the nuclear waste management team has learned two important lessons:

(1) The problems of high-level nuclear waste management are so complex and have so many ramifications that no one person or group of persons can possibly have all the answers.

(2) Flexibility is essential in any viable nuclear fuel cycle and waste management plan. No option should be foreclosed permanently until the implications of this foreclosure are thoroughly understood. However, this flexible approach should not prevent the development of a viable program for permanent disposal of high-level waste.

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JET PROPULSION LABORATORY *California Institute of Technology • 4800 Oak Grove Drive, Pasadena, California 91103*

October 10, 1977

Dear Colleague:

Enclosed is a copy of a report entitled, "An Analysis of the Back End of the Nuclear Fuel Cycle with Emphasis on High-Level Waste Management." I've sent you this publication because I believe that you will be interested in the subject matter.

This report summarizes the results of a research project conducted by the Jet Propulsion Laboratory for the Office of Science and Technology Policy. We have examined the programs and plans of the U.S. government for the "back end of the nuclear fuel cycle" to determine significant technological or regulatory gaps and inconsistencies.

I hope that this report is useful to you.

Sincerely,

T. D. English

Thomas D. English, Ph.D.
Project Manager
Nuclear Waste Management

Enclosure

Telephone 354-4321 *Twx 910-588-3269* *Twx 910-588-3294*