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SPACE DISPOSAL OF NUCLEAR WASTES: SOCIO-POLITICAL ASPECTS

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PREFACE

This report is the result of a study funded by the National Aeronautics and Space Administration through the Ames Research Center to assess the feasibility and implications of a hypothetical decision to dispose of long-lived high-level nuclear wastes, or some portion of these wastes, in outer space. It is important at the outset to delineate the boundaries of the study and to clearly state the premises that were stipulated and distinguish them from those areas that were more thoroughly explored.

The focus of the research has been on the social and political implications of a decision to implement the space disposal idea, and on the various social and political structures that would be associated with it. The technical work that has been done (primarily under an independent, but associated intergovernmental personnel agreement with Dr. Gene I. Rochlin) was oriented primarily towards setting out the boundaries of a model for the nuclear industry and of the associated fuel cycle services so that accurate estimates for high-level waste quantities and characterization could be made. Owing to the large number of possible decisions that might be taken regarding the post-reprocessing treatment of wastes, however, less accurate estimates could be made of the quantities that might be involved in space disposal operations. Accordingly, a semi-parametric approach was adopted, with the program characterized at two extreme and one medial level of operations: 10, 100, or 1000 shuttle launch missions per year.

It was not possible to perform an independent review of presently considered space technologies that might be applied to waste disposal, nor to attempt to assess the contributions that might be made by some of the more advanced launch vehicles that have been suggested. Given our limited resources and the small amount of technical expertise in launch and vehicle technology available to us, it was necessary to assume a technology and mission profile that was already in the literature. As extensive studies have been made in the past of operations using the space shuttle orbiter, both by NASA and in waste management review studies, this was the mission adopted for this study as prototypical over the time period of concern. This is a somewhat restrictive assumption, because a totally committed waste vehicle would have a more favorable payload to vehicle weight ratio than could any adaptation of a multi-purpose vehicle such as the shuttle orbiter. However, given the range of assumptions used in constructing the semi-parametric launch models used for the study, we seriously doubt that a shift in vehicle would substantially affect our conclusions as to the social and political implications of a space disposal program.

There is no site-specific social impact chapter here. To do a detailed impact analysis on even such a narrow and localized stratum of population as that surrounding the present launch site at Cape Kennedy would require far more in time and resources than could possibly have been allotted to this study. Moreover, as have often been stated, the social or political scientist works in a real world situation that is not subject to ready abstraction. The impact on any specific population is, in fact, specific to that population in its exact situation. More generalized rules can be abstracted, but they must be applied with great caution.

We do not attempt to speak with precision about that which we were unable to explore in detail. The level of analysis, therefore, varies from section to section within this report. With regard to extant technologies and past and present policy apparatus, some detailed and fairly specific comments could be made. But with regard to future decisions and future social and political impacts, the analysis is generic, not specific, and should be applied with some caution. A careful analytic group is strictly a non-prophet organization. What has been done is not to attempt to predict outcomes or future, but to sketch out what experience and analysis have taught us about the responses of and impact on both selected and general populations under similar circumstances.

The report is organized as follows. In Part I we outline the background political and technical data that are needed for performing the impact analysis. Both in a historical policy context and in terms of the present and likely future development of nuclear power technology and waste management, we outline the preconditions that would have to be met for the space disposal option to be given serious consideration.

In Part II we describe the potential role of the space shuttle program in the management and disposal of high-level wastes. This includes not only the technical, but also the social, political, ethical, and public environments within which the proposed program would operate. A careful analysis is also made of the technical operation of the system, and of the technical limitations imposed upon the program by the operational procedures of the commercial nuclear power industry.

Part III discusses potential secondary impacts upon society of space disposal operations. The prevention and management of accidents as well as their direct effects if they should occur are included here. For incidents and accidents are likely to occur in even the best designed systems, and failure to provide for their occurrence can be a serious fault. A fairly specific look at the causes and consequences of such failures is taken here, as well as an examination of the consequences of building up an operational structure committed to a very low failure rate.

Part IV continues the discussion of secondary impacts with a further investigation of the impact of space disposal operations on social experience. The discussion here is further extended to encompass tertiary impacts; cultural and political responses to the secondary effects of changes in social experience. As most of the effects discussed in this section, for example distribution of jobs and social privilege, require considerable specific detail for analytic conclusions to be drawn, the discussion here is largely generic and conceptual. What is set out is not an explicit description of a particular set of responses, but a more wide-ranging discussion of the potential for generating classes of response.

We have also appended to this report a section on the design of error-correcting organizations. For, with space disposal of highly toxic radionuclides, we would enter upon a system where there would be a very high price to pay for even the first major failure. Any organization designed to operate or manage space disposal operations would have to have built within it the potential to detect and correct incipient failures before they occur. That such requirements are by no means trivial of fulfillment is described in this appendix.

It is also worth setting out here the assistance that was given to this study by the multiplication of effort owing to other activities of two of its participants. Dr. Dan Metlay was, in addition to his work on this study, a member of a U.S. Nuclear Regulatory Commission Task Force on Criteria and Goals for nuclear waste management regulation, which gave him access to and information from a large number of persons whose policy or legal involvement with such a program would be great. He also contributed to this study several chapters derived from work done on his dissertation in political science. Dr. G. Rochlin was, during a portion of this study, a member of an American Physical Society study on the nuclear fuel cycle, giving him access not only to the most up-to-date technical and economic projections for nuclear growth, but also access to experts in every field of the nuclear industry related to waste management. None of this large amount of extra work contributed to the study was done at NASAs expense. It amounts to a gratuitous, and fortuitous, contribution.

After reviewing all the information available to us, we have come to a largely negative conclusion regarding the potential value of a space disposal program, and negative on both operational and socio-political grounds. On the operational level, it appears that there are a large set of preconditions that would have to be met before it would make sense to invest the large amounts of money and technical and industrial effort the program would require. Unless these preconditions were met, space disposal would simply not reduce the real and perceived risks from long-lived components of the wastes to a level that would justify the effort involved.

On the socio-political level, there are grave doubts as to both the possibility of operating the institutional and organizational support systems at the required levels and growth rates and so to the possible impact on NASAs other missions and goals even if the operations were successful and free of failures.

On a medieval map of Britain, a large area to the north is marked with the legend: "Here there be wolves." Although this provides no specific guide for the traveller to use in evaluating a safe route through the area, nor a quantitative assessment of the risks involved, it does serve some purpose in raising a note of caution. So it is with a generic study such as this one. No specific policy recommendations are made here as to whether or not a space disposal program should be implemented, nor as to which program might be the best to pursue. Some of the risks and costs that might be entailed are set out, and some of the areas requiring further investigation before a wise decision could be made are sketched out. But we do raise a note of caution. It is our view that NASA as an institution would run far from negligible risks in the operation of a space disposal program, and that consequently it should, at the minimum, investigate carefully whether it is the appropriate agent to manage such a program even if it were to be implemented.

PART I

BACKGROUND FOR THE ANALYSIS

INTRODUCTION TO PART I

In Part I of this study, we introduce the preconditions for the technical and political decisions that would have to be made in order for the space disposal program to be given even serious consideration as an option on the same footing as such current plans as disposal in salt beds. This material supplies the necessary background for the discussion in Part II of this report of the potential role of the NASA shuttle program in nuclear waste disposal, and the analysis of not only the technical and scientific, but the social and political milieu that would be required for a decision to move towards implementation.

Chapter 1 focuses on the past history of radioactive waste management in the United States, for its is important in setting up the social and political context to understand how and why it came to be that nuclear waste disposal remained an unresolved problem as long as it did. Secondly, one should be cognizant that future decisions will not and cannot be taken in an atmosphere free of the clouds of old battles over wastes. No waste disposal program, including this one, can ever operate with the blank slate of ten years ago.

Chapter 2 sets out the ethical and moral concerns over long-lived toxic radionuclides that form the fundamental motivation for consideration of such expensive and high-technology disposal programs as transmutation or space disposal. For, were it not for our concern over the future and their well-being, it is clear that waste disposal would not be considered a major problem. Getting the wastes out of the biosphere for our lifetimes would be no great technical feat. Even for the lifetimes of our children, there are many ways to emplace the wastes to preserve them from harm. But over the very long lifetimes of the transuranic isotopes as potential hazard, our uncertainty as to geology, culture, social and political development, and demography raise to a high level our uncertainty about the future's ability to recognize an untoward event, let alone to reduce its consequences.

Chapters 3 and 4 address the technical preconditions for space to become a chosen option. In Chapter 3, we discuss the growth of the nuclear power industry and its associated wastes, as well as the supporting fuel cycle facilities that will be needed. Within this context, we examine the several ways of processing spent fuel that would reduce the waste masses to quantities manageable by a hypothetical space disposal program. In Chapter 4, this information is used to derive a set of technical criteria for efficiency of fuel cycle operation that would allow the space program to respond to the concerns raised in Chapters 1 and 2. For, unless there is a major reduction in the terrestrial inventory of transuranic isotopes, and particularly the isotopes of plutonium, it would simply not make sense to invest the resources that would be required, technically, economically, politically, and socially, to make the space disposal program a reality.

CHAPTER I

HISTORY AND INTERPRETATION OF RADIOACTIVE WASTE MANAGEMENT IN THE UNITED STATES

Introduction

This is an interpretive history of radioactive waste management in the United States. It is interpretive because it seeks to tease out the significant strands of policy and organizational behavior rather than to give a complete chronicle of past actions. As a result, there is not a detailed description of what occurred in every facet and phase of the Atomic Energy Commission's involvement in waste management. Instead, some aspects have been emphasized and others hardly touched upon at all.

This allows us to focus on broad themes of behavior and upon variations on those themes. We can highlight those things which stand out as being particularly critical in the history of waste mangement. From discussions with a number of people, both practitioners and observers, we believe that many, if not all, of the important patterns of how waste management policy was determined and implemented have been captured. Nevertheless, interpretive history is often highly error prone. It depends upon the analyst's ability to scan sensitively the entire history to select for comment those parts which are, in fact, essential to a fair and complete understanding of the whole.

Historically, waste management decisionmaking has been characterized be periods of profound unconcern interspaced with rare moments of intense interest. Lacking the "sex appeal" of reactor development and the "pork barrel" quality of other segments of the fuel cycle, waste management became, organizationally and operationally, a residual category. After a brief synopsis of the significant events in the history of waste management, we develop this history's significant themes. Examples from the past are marshaled to illustrate them. Some lessons are drawn which need to be recalled by future designing waste management systems.

Origins and Background

The creation of today's unwanted radioactive waste legacy resulted from many small, past actions, premised on limited vision and constrained by few resources, severe time pressures, and overwhelming competing priorities. Nowhere is that description more accurate than in the case of the wastes generated by the Atomic Energy Commission's military program.[1]

The AEC has operated three facilities--at Hanford, Washington; at Savannah River, South Carolina; and at the National Reactor Testing Station in Idaho--for the purpose of producing plutonium in reactors for the weapons' program or to process irradiated fuel for the experimental reactors as well as from the reactors of the Nuclear Navy. As of 1974, these wastes, in the form of liquids, salt cakes, sludges, crystals, and calcine granules represent some 85 million gallons.[2]

The production of wastes is an inextricable part of the operation of those facilities; as soon as fission takes place--whether it be in a production, research, naval, or civilian nuclear power reactor--wastes are produced and the need to manage them becomes manifest. Different strategies for management have been adopted at each of the three AEC facilities. At Hanford, the waste streams have been neutralized and then stored in single-walled carbon steel tanks. The non-boiling wastes are now being solidified in their tanks. The self-boiling wastes are being fractionated to remove the long half-life heat generating isotopes of cesium and strontium. The waste that remains is non-boiling and is being solidified. At Savannah River, the neutralized waste solutions are stored in carbon steel tanks that sit like cups in saucer-like carbon steel shells. At Idaho, the wastes, initially stored in stainless steel tanks, are calcinated (solidified) and are then put into stainless steel bins which are housed in concrete structures. The solidified wastes can be easily retrieved. Present and future plans for these wastes are summarized in Figure 1.1.[3]

Waste management operating experiences at each of these three facilities have differed as well. The worst record has been at Hanford. Beginning in 1956, a total of 18 separate leaks have been detected in which 450,000 gallons of liquid entered the environment.[4] An unknown number of potential leaks were forestalled by transferring the waste solution from weakened tanks to others possessing greater strength. The secondary containments used at Savannah River have prevented major releases to the environment; less than 100 gallons of waste have escaped into the soil there.[5] The best record has been compiled at Idaho. There the use of stainless steel tanks has eliminated the need to neutralize the waste stream emerging from the reprocessing plant. This, in turn, has made it possible to calcinate the wastes. The now solid waste can be stored and handled easily; the only precaution which must be taken is to isolate the highly leachable solids from water in the environment. To date no accidents have been reported at the Idaho facility.[6]

The basic conceptual framework for civilian waste management, which still dominates most people's thinking, emerged from a report by the National Academy of Sciences' Committee on Waste Management in 1957. The Committee noted that "the most promising method of disposal of high level waste at the present time seems to be in salt deposits."[7] Four years later, in another report the same advisory committee remarked that "Experience both in the field and in the laboratory on the disposal of wastes in salt have been very productive and well conceived; plans for the future are very promising."[8]

This imprimatur of the Academy stimulated a research program under the direction of the Oak Ridge National Laboratory (ORNL). A major part of that program, called Operation Salt Vault, was to determine the consequences of exposing bulk salt to radiation and heat. The site of the experiment was an abandoned salt mine near Lyons, Kansas. Spent fuel elements were used to represent the solidified waste because the latter was not available at the time. Electric heaters simulated the thermal output of the waste. (Because of the experimental character of Project Salt Vault, retrievability was built into its design from the very beginning.)[9] Efforts were made by the ORNL staff to conduct the effort in

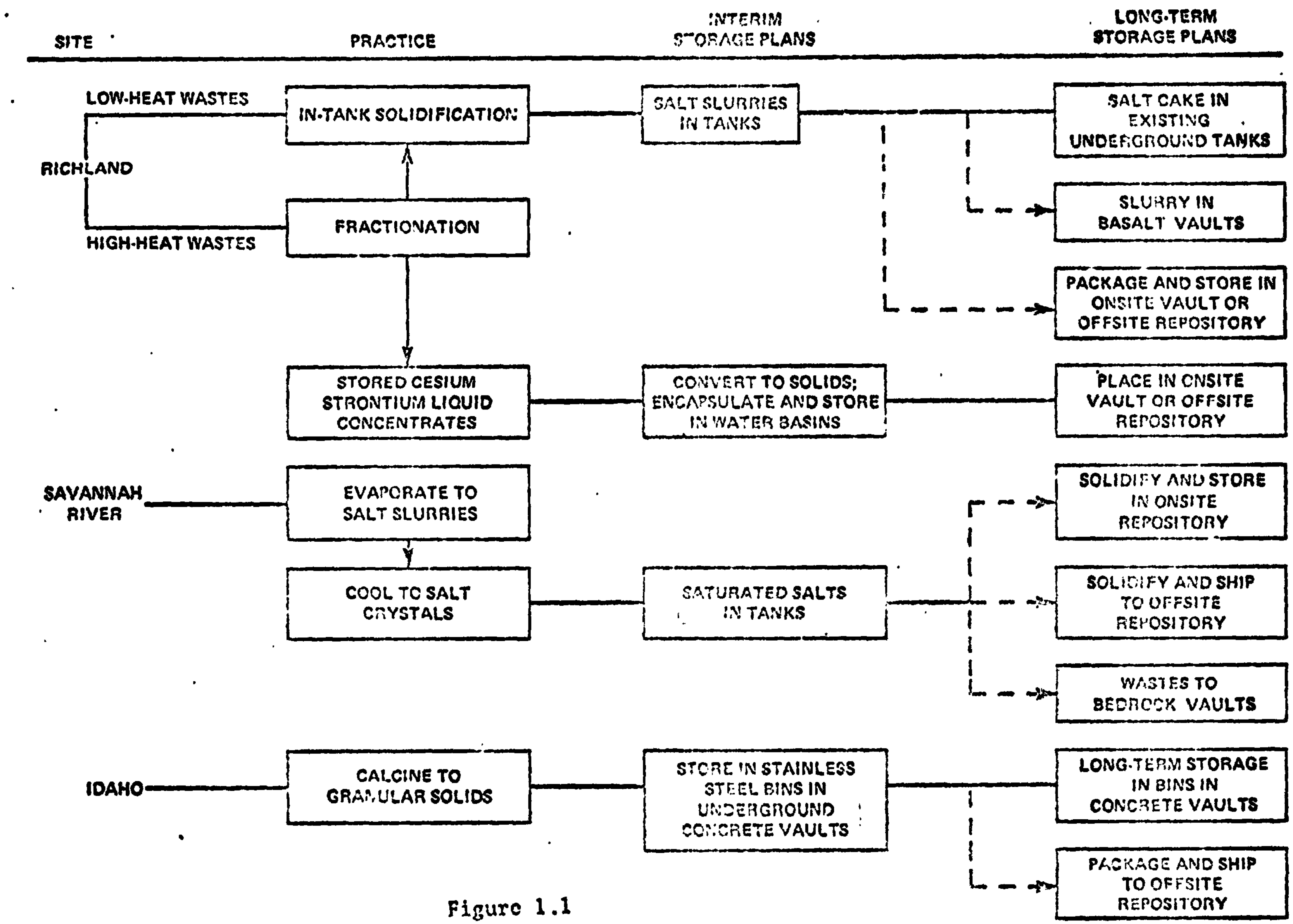


Figure 1.1

COMPARISON OF PLANS FOR LONG-TERM STORAGE
OF HIGH-LEVEL RADIOACTIVE WASTES

WOOD

Note: Solid lines indicate current plans; dotted lines indicate alternates.

full view of the Kansas population. Consultations were held with the local citizenry before the project began. Once the experiments started operating, regular tours were conducted in which the general public could visit the mine. The reversibility of the effort and the openness of its implementation produced a climate of acceptance. If not loved by all, as some participants claim, at least Project Salt Vault did not evoke fears and horrors in the minds of the central Kansas population. Despite its initial promise and ultimate success in producing data, Project Salt Vault never really enjoyed much support from the Reactor Development Division at the AEC. Funds had to be "bootlegged" by ORNL from other projects simply to keep it going, but if the ORNL salt experiments were initially neglected, events soon conspired to propel them into view.

A fire at the AEC weapons facility located in Rocky Flats, Colorado, gave rise to a large volume of low level, plutonium contaminated debris. Following its standard operating procedures, the Production Division of the AEC forwarded that waste to the Idaho Reactor Testing Station for interim burial. That action outraged Idaho's Senator Frank Church, who saw no reason why his state should become the dumping grounds for Colorado's waste. Church acted and extracted a commitment from AEC Chairman Glen Seaborg that all the waste stored in Idaho would be removed by 1980.[10]

At the same time, steps were being taken to formulate and to formalize a regulatory policy concerning commercially generated wastes. Up to that point, whatever policy existed had been more or less ad hoc, a result of a set of individual decisions such as those made in the licensing of the Nuclear Fuel Services reprocessing plant and the five low-level commercially operated burial grounds. That first systematic attempt to develop a waste management policy led ultimately to the adoption of Appendix F to 10 CFR 50.[11] Among its other provisions, the regulations provide that solidified wastes shall be "transferred to a Federal repository no later than 10 years following the separation of fission products from the irradiated fuel." Thus, the Rocky Flats fire and the now officially acknowledged need for a repository which stimulated the Commission to transform the early experimental efforts at the Kansas salt mine into a demonstration repository.[12] If necessity forced the decision, it did not seem premature at the time. In the words of one of the AEC managers; "It was time for ORNL to put up or shut up. Either they should design a facility or stop claiming it was technically possible."

The Commission considered locating the facility in Kansas, Michigan, and New York. None of those three alterantive sites possessed any great geological advantage over the others: each appeared quite suitable. Three factors swung the decision in favor of the Lyons, Kansas, site:

1. "Detailed information on the area had been gathered as part of Project Salt Vault."
2. A sense of confidence in receiving a "favorable reception on the part of local and state officials and private citizens."
3. The recognition that "necessary investigations to prove out the acceptability of (the other) sites would result in considerable delay estimated on the order of two years."[13]

That June 12, 1970, decision was followed five days later by an AEC press release that explicitly stated that the selection was tentative.

That few people truly believed that claim was a harbinger of things to come. Among those who reacted negatively was the National Academy of Sciences' Radioactive Waste Management Committee meeting that very day in Lawrence, Kansas, to consider the suitability of the Lyons site. The press announcement clearly suggested to them that they were being preempted and led to the formation of long lived and highly damaging resentments. It was hardly an auspicious beginning.

It was all down hill from there. Relations between the AEC Reactor Development Division under Milton Shaw and ORNL were never pleasant; the Lyons' project certainly did nothing to improve them. The managers at AEC headquarters complained that the Laboratory directors never fully appreciated the fact that they were constructing an operational facility, not designing a research center. Increasingly, the AEC Reactor Development Division personnel felt that calculations that had been presented as complete and sophisticated were actually "back of the envelope" efforts. A perceived combination of sloppy technical work with disregard for the pragmatic realities of the project quickly soured the Reactor Development Division managers on ORNL.

Nor was the ill will one-sided. For their part, scientists from ORNL accused the headquarters bureaucrats of behavior which could be termed technological arrogance. The Oak Ridge scientists observed the fund of good will that they had built up among the local population over many years being dissipated. In their view, the "outsiders from Washington" treated the local scientists at the State Geological Survey and at the State University in such a patronizing and condescending manner that it bordered on contempt. Perhaps as important, at least subconsciously, the ORNL scientists saw themselves being ignored and pushed into the background when it came to policy decisionmaking.

However, the tension which existed between ORNL and headquarters was insignificant compared to the fundamental cleavages that developed between the Kansas scientists and the AEC. The leader of the technological opposition was William Hambleton, the Director of the Kansas Geological Survey and a member of the National Academy of Science panel convened to assess the Lyons' project. Hambleton's ire at the AEC was first aroused in two initial meetings held between the Commission and the Academy panel in the spring of 1970. At that time, he felt that the Commission was insensitive in their dealings with the Academy in general and with him in particular.

Hambleton's objections were not entirely caused by personal pique. He was convinced that the ORNL calculations were too primitive to allow any statement about the safety of the repository to be made. Hambleton was concerned that not enough was known about possible radiation damage to the salt, about waste canister movement in the salt, and about retrievability. Most importantly he was skeptical about the calculations on heat transfer extrapolated from a two dimensional to a three dimensional model.[14]

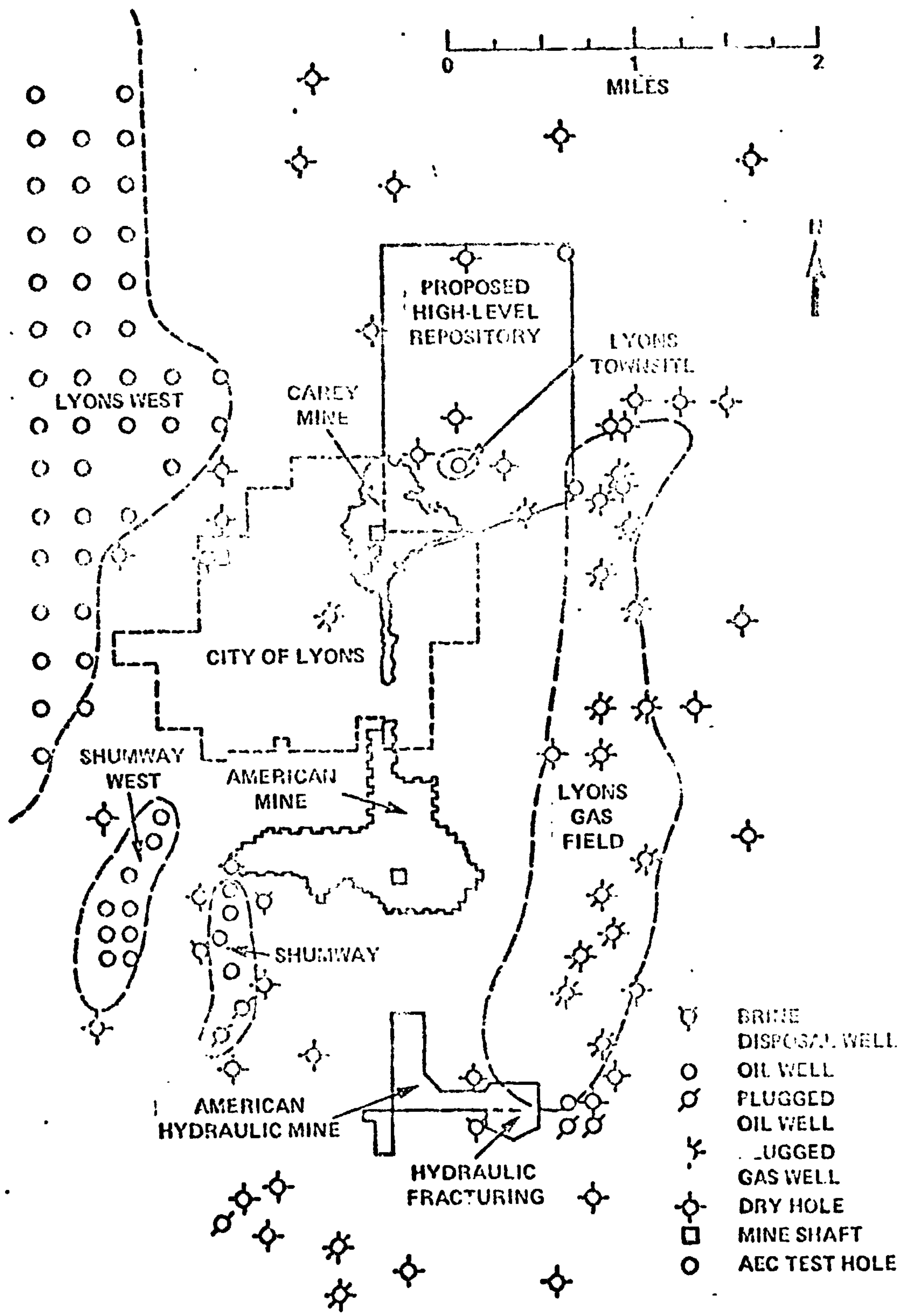
Those scientific objections provided a basis for political opposition. The political forces were led by Kansas Representative Joe Skubitz and by Governor Robert Docking. Together they attacked peripheral issues in the hope that the project would collapse. The optimistic forecast of the AEC staff for ready public acceptance of the Lyons' Project proved to be extraordinarily ephemeral. While the Kansas opposition never succeeded in stopping the project, it scored something of a triumph when the Congress passed an Amendment in 1972 to the AEC Authorization Bill. The amendment sponsored by Kansas Senators Pierson and Dole, but instigated by Skubitz, prevented the AEC from implementing the Waste Repository Project until a distinguished advisory commission certified that the project was safe.[15]

The AEC, however, viewed these attempts at political harassment almost disdainfully. They proceeded confident that despite some unresolved problems a technical solution could be found. None of their studies turned up any information that altered that view. To be sure, there were more bore holes from gas and oil exploration than had been expected; but given time and resources those could be successfully plugged. There was some concern about some "water" used in a neighboring mine as during an injection/extraction operation which was accounted for. But the volume was small and posed no danger. In short, the AEC proceeded down the road to implementation carrying out confirmatory tests that would fulfill the conditions that the NAS had imposed in their report tentatively affirming the suitability of the Lyons' site.

Then in September, 1971, the AEC Reactor Development Division was informed that the American Salt Mining Company had undertaken a massive effort using hydraulic fracturing in a mine two to three miles south of the proposed repository. (See Figure 1.2) It was initially thought that the outcome of that action would be to remove virtually all the salt in that area. If that were the case, subsidence followed by the formation of "Lake Lyons" was a definite possibility. Such a "lake" would threaten the integrity of another American mine which in turn was located a mere 1,700 feet from

Figure 1.2

THE LYONS, KANSAS SITE



(1008D)

an extension of the Carrie mine which again in turn was part of the repository itself. This potentiality was the straw that broke the Lyons' project. The Reactor Development Division Manager of the program returned to Washington convinced that the AEC was "now in a no win situation." No technological fix could ever be developed that would convince the public that the danger was minimal.

This turn of events was soon followed by a warning from the Nixon White House to the Commission: do nothing to rock the boat this close to the election. The new Chairman, James Schlessinger, and a new Commissioner William O. Doub were especially sensitive to this plea. Slowly, Lyons faded into the background. By February, 1972, the repository project in Kansas was officially dead.[16]

The Commission had been burned by the waste issue. Schlessinger reacted by refusing to consider any plan which involved burials at depths less than 10 miles and by pressing for consideration of exotic waste management alternatives such as transmutation and space disposal.[17] However some new practical concept had to be developed in the short run. The Commission could not afford to be seen as having no waste management policy. Under the direction of the new Director of the Division of Waste Management and Transportation, Frank Pittman, the notion of an Engineered Retrievable Surface Storage Facility (RSSF) was developed. Mausolea would be constructed in the west for the storage of AEC generated and commercially generated waste. Once a permanent repository was developed the waste could be transported to it.[18]

This policy, announced in May, 1972, survived one challenge 18 months later. The General Manager proposed that instead of building an RSSF, the solidified waste be stored at the reprocessing plant until a permanent repository was established. In large part because of the objections of the Director of Regulations, the change in policy was rejected by the Commission.[19]

Nevertheless, the RSSF concept was not to be implemented. In September, 1974, a draft environmental impact statement on the project was issued. Comments received from environmental groups and from state and local governments were generally critical. The coup de grace, however, was delivered by the Environmental Protection Agency. In its comments EPA concluded:

> The development of an environmentally acceptable system for permanent disposal of commercially generated radioactive waste would appear to be a high priority program that is essential for the development of nuclear power. However, the draft statement does not contain adequate description of a program to develop such a permanent disposal system, nor does it reflect either the priority attached to this overall program by the AEC nor an indication of the resources required. Because of the overwhelming need to develop an environmentally acceptable ultimate disposal method and the realization that there is a risk of failure in any research and development effort, we believe that work on promising alternatives should be pursued concurrently.
>
> A major concern--the employment of the RSSF concept--is the possibility that economic factors could later dictate utilization of the facility as a permanent repository, contrary to the stated intent to make the RSSF interim in nature. Economic factors would consist mainly of the fiscal investment attendant to its construction and the activities which arise in the commercial segment of the economy to support its operation. Since there are controlling environmental factors that must be considered before final disposition of the RSSF, it is important that these factors never be allowed to become secondary to economic factors in the decisionmaking process. Vigorous and timely pursuit of ultimate disposal techniques would assist in negating such a possibility.[20]

The draft environmental statement received EPA's lowest category of evaluation. Significantly one of the first actions taken by Richard Seamans after he became Administrator of ERDA was to withdraw his request for funds to build the RSSF. Like the Lyons' salt mine before it, the RSSF was officially dead.[21]

This historical narrative of the AEC's involvement in radioactive waste management was presented to provide a summary of what transpired in the past. Given this outline we can now discuss the broad themes of waste management policy.

Underlying Themes of Waste Management Policy

Specialization has the virtue of bringing to bear expertise in solving problems. Specialization can also, however, lead to what the sociologist Robert Merton has called "The Trained Incapacity to Think."[22] In either case, specialization furnishes a particular lens through which the problems are viewed and solutions reached. It is hardly surprising, then, that a technologically based agency has come to see the solution of the radioactive waste "problems" in terms of a technological fix. Public and private statements of key agency decisionmakers support this view.

For instance, Dr. J. A. Leiberman, Chief of the Environmental and Sanitary Engineering Branch of the Reactor Development Division, testifying before the Joint Committee on Atomic Energy, as early as 1959, said that:

> Although one has to be careful to distinguish between aspiration, reality, and speculation, it is my strong feeling that the development program has thus far found [technical] solutions to some of the waste problems that...and at least indicated solutions to others.[23]

Dr. Frank Pittman, Director of the Division of Waste Management and Transportation told an audience of the American Nuclear Society in 1972: "We do have today (in the RSSF) the answers needed for safe management of commercial high level radioactive waste."[24] John Bartlett of the Waste Alternatives Evaluation Program at the Battelle Pacific Northwest Laboratory told the Task group: "There is no technical problem, the waste can be managed; the crucial problem is public reception of radioactive materials." Even the worst blunder in waste management history, the Lyons' Project, was theoretically possible. Bill McClain, the ORNL mining engineer on that effort, was asked by the Task group whether the laboratory could have handled the problems in Kansas. He replied: "Of course, it was technologically possible." One gets a strong impression, then, from reading the public record and from talking with agency personnel that the AEC personnel think that if they were just given enough money and left alone they would solve the "problem" expeditiously and to virtually everyone's satisfaction.

This position is held despite demonstrated failures because the people who hold it are specialized. They have come to view problem solving in particular--not necessarily wrong or evil--technological way. Their entire training, sense of structure, and socialization has reenforced their conviction that problem solving is dependent merely on additional doses of technology. In this case, they say that the waste management problem can be solved by designing a technological system which can isolate the waste from the environment indefinitely.

Although such a technological fix is not theoretically impossible, experience has shown, in the case of other complex technological systems, the belief that technology alone is enough is more often than not simply illusory. For example, the development of garbage disposals was perceived as being a technological solution to domestic inconvenience. The result was pollution of rivers. It was then necessary to find ways of purifying the rivers to maintain water quality. One means was to use bacteria; but a great quantity of oxygen was required for the bacteria to destroy the organic pollutants. Thus a technique had to be found to oxygenate the rivers. And so it goes.[25] Complex technologies, like nuclear waste management, are by their very definition hard to bound. To the extent that such circumscription is difficult a technological fix is impossible. Technical personnel and agency leaders seldom fully appreciate this fundamental aspect of the waste management problem: Any policy adopted must treat a wide range of issues not simply the design of the technological core of the system.

Of course one can posit circumstances under which decisionmaking need not include non-technological factors. (For instance, institutional questions of implementation.) If the system could guarantee the complete isolation of the waste indefinitely then a bounded technological fix could be quite conceivable. Yet, for any such system to be adopted, as opposed to proposed, two conditions must be fulfilled. First a high degree of agreement must exist as to how the important parameters of the system, i.e., degree of isolation, are to be measured: there has to be a common, accepted, metric of evaluation. Second there must be a strong consensus over what operations lead to the "correct application of the metric," i.e., what tests accurately measure the degree of extended isolation of the waste. Absent those two conditions, no technological solution can find broadly based acceptance. Lack of broadly based acceptance implies by its very existence that a technological fix is not viable.

Implicitly, the AEC technical personnel and decisionmakers recognize this lack of technological viability, and this prompts their complaint that the system is too open. They say that environmentalists are irresponsible; politicians are simply trying to grab headlines to be reelected; the general public is uninformed and irrationally fearful about things nuclear. If these extraneous influences were removed, then something could be accomplished, i.e., uncertainty could be resolved subjectively and a technological solution could be implemented (imposed).

It is not hard to see why the AEC directors strained to decouple the technological core from other aspects of the system. To succeed in doing so--in effect to simplify the problem--conserves such scarce organizational resources as time, thought, and money. Moreover, to consider other aspects of the "problem" would force the agency outside the bounds of its expertise, of its specialization, of its trained incapacity. To accept the notion that a technological fix is not possible is ultimately to agree that the control of the problem solving effort should be shifted away from the AEC. It is hardly surprising that strenuous efforts have been made to preserve the illusion of a technological solution.

Institutionalizing Belief in a Technological Solution

Early thinkers on waste management recognized that radioactive waste had to be managed in ways altogether different from other industrial wastes. The idea of dumping the waste into nearby bodies of water was, for example, rejected almost out of hand. Moreover, the record indicates that as late as 1955 the AEC had not succumbed to the easy assumption of a technological solution. For instance, A. E. Gorman of the Reactor Development Division speaking to the First National Academy of Science Advisory Committee on Waste Disposal, about the AEC Production Facilities said:

> Looking backward we know of the mistakes that many industries made in assuming that the disposal of waste was simply a backdoor problem that anyone could handle. To some extent because of our geographically isolated locations, it has been possible to sweep the problem under the rug, so to speak. But those of us who are close to it are convinced we must face up to the fact that we are confronted with a real problem.[26]

Dr. Leiberman of the Division of Operational Safety noted "I certainly hope I can disabuse you of the idea that we have any solution that will solve immediately the problems of waste disposal."[27] Yet, if that NAS study began on a note of caution it ultimately provided the major support for the technological optimism that developed in the agency. Although the writers of the NAS report were careful to note the need for further research they stated categorically that "the committee is convinced that radioactive waste can be disposed of safely in a variety of ways and in a large number of sites in the United States."[28] Further, they stated that "disposal in salt was the most promising method for the near future."[29] The consequences of such judgments have been great. A person who has been in the waste management program for a number of years said in an interview that "The NAS report did instill a sense of complacency in the minds of the people dealing with waste management. In part because of it we felt that a solution would be available whenever we needed it." However it is clear that the NAS study did more than simply instill confidence that waste disposal could be accomplished. It also established the boundaries of the problem. It suggested that all that is required is a technological fix.

That fundamental premise was reenforced in an extended set of hearings before the Joint Committee on Atomic Energy starting in January, 1959. The hearings opened with a statement by Able Walman of Johns Hopkins University. Walman refused to minimize the problems of waste management. He noted:

> We have to have continuity of government supervision whether long or short, whether strong or weak. This is not a problem, in other words which can be tackled from the standpoint of temporary expedience. It is a problem which will require a deep governmental supervisor, a... very long and continued uninterrupted supervision over the fate and location of these materials.[30]

Nor did Walman suggest that the problems were simply technological.

> It is a rather interesting if subtle observation that in conversation with industrialists interested in nuclear fission power they consider the waste problem to be quite unimportant I believe for psychological reasons. It is unimportant to them because they are not responsible for its management and hence its cost.[31]

Walman's testimony led Representative Chet Hollofield to comment:

> So it would be accurate to say that the problem of permanent disposal of high level waste has not been solved; that it is in the state of suspension; that we are holding these high level wastes to the extent of many millions of gallons in temporary custody and that no decisions have been made as to the final disposal of the high level waste.[32]

However those notes of caution and skepticism were virtually the only ones to be heard as the hearing progressed. One expert after another from the AEC, from the National Laboratories, and from industry, testified that a technological solution to the problem was possible and was, in fact, the only aspect of the question that needs to be addressed. Their approach was typified by the comments of Herbert Parker, the Manager of the Richland Facilities. When asked how long he thought the tanks at Richland would last, Parker replied:

> I will answer that question by saying that for a longer time than any operation heretofore contemplated by man, these wastes will have to remain isolated from the environment and until the time we create a better way the isolation will be in tanks of this character. This does not mean it will have to be in this particular tank. In other words if the tanks we have turn out to be prepared at the right time with an alternative set of tanks and pump the liquids into the new tanks. We have extensively moved the liquid from one tank to another and are persuaded we can do this operation with perfect safety.[33]

Although Parker does not say so explicitly the tenor of his statement when read in its entirety suggests that he sees little wrong with maintaining that strategy into the indefinite future. His views probably represent extreme endorsement of a technological fix for waste management. The other witnesses while more subdued in their views are clearly philosophically aligned with the position which Parker had championed.

The cumulative impact of the NAS report in the Joint Committee hearings was to legitimate a technological approach to waste management. Over the years it evolved into an official doctrine of the agency. There is no evidence that its validity was ever seriously questioned or even reassessed. More significantly, the search for a technological solution has persisted and the belief in the efficacy of a technological fix has been maintained, often in the face of disconfirming evidence.

In particular, the AEC has continued to pursue a technological fix despite evidence that non-technological factors are an integral part of the waste management system. The approach taken in dealing with the leaks at Hanford illustrates that point well. The tanks' potential for leaking compelled the operators to implement a system to detect failures in the tanks. The system was a highly routinized one in which volume levels were measured by technicians and compared against previous levels. Although standard operating procedures were enforced to insure the measurements, no procedures were developed to force the requisite comparisons. Thus, it was only a matter of time before a leak would go unnoticed. In the spring of 1973, Tank 106T leaked 115,000 gallons into the environment. Excerpts from the chronology contained in the official report of this incident tell the story best.

> On May 2 the first weekly liquid level reading of Tank 106T after the completion of the pumping operation was taken it was recorded at 178.9 inches. The information was recorded in the static tank farm inventory log and left on the office desk. The day shift supervisor has stated that he did not review the information because of the press of other duties.
>
> On May 7, the weekly liquid level reading for Tank 106T was recorded at 174.0 inches. The information was logged in the static tank farm inventory log in the day shift supervisor's office. He did not review it.
>
> On May 14, the weekly liquid level reading for 106T was recorded at 167.9 inches. The information was logged in the static tank farm inventory log. It was not reviewed by the day shift supervisor.
>
> On May 21, the weekly liquid level reading for 106T was recorded at 160.4 inches. The information was logged in the static tank farm inventory log. The day shift supervisor did not review it.

> On May 30, the weekly liquid level reading was recorded at 152.7 inches. The data was logged on the static tank farm inventory log. The day shift supervisor did not review it.
>
> On June 4, the weekly liquid level reading for Tank 106T was recorded at 149.2 inches. It was logged in the static tank farm inventory log. The day shift supervisor did not review it.

Similar failures took place in the dry well monitoring system that was a redundant back up for the volume measuring system. Thus the leak which began on April 20 was not confirmed until June 6, a period of 6 weeks.[34]

After the leak of Tank 106T, a set of new procedures were adopted. Liquid level measuring instrumentation was computerized; readings were made more frequently. Tank transfers were monitored more precisely. "A rigorous policy of operating equipment according to the procedure was implemented to insure compliance with approved procedures."[35] Several organizational changes were carried out as well. Management responsibility was consolidated; internal audits were reenforced; a division of quality assurance and safety was created; more aggressive management was recruited.

It is hard to assess the effectiveness of those changes. The two years in which they have been in operation is hardly time for a fair test. Nevertheless, they do seem to have performed well. Yet it is clear that the changes do not treat the root causes of the failure to detect leakage in the 106T Tank. That failure was due to non-technological factors. In the words of the official report.

> There was no effective redundancy in the system to assure that a leak undetected by those primarily responsible for detection would be detected by somebody else, or to alert management's attention to any breakdown in the system.[36]

Moreover, by increasing the technological complexity of the detecting system without increasing the redundancies in the non-technological elements needed for implementation, the overall reliability of the system is likely to decrease. Such an outcome is almost an inevitable result of thinking that focuses primarily on technological solutions.

The pattern of behavior at Hanford is really not atypical. One could just as easily point to the operations at Savannah River, to the Lyons' Project, and to the RSSF. In each case, directors focused attention primarily on the technological aspects of the endeavor and largely ignored the non-technological issues and concerns. In the end, it was those latter factors largely determining the outcome. Experience should have taught the AEC directors a lesson: its vision in dealing with waste management problems had to be broadened. Only recently has there been evidence that such lessons have been learned.

Not only has the past demonstrated that faith in a technological solution may blind decisionmakers to other important facets of problems, but also the past has shown that even solutions to technological problems may be only temporary. Again, the experience at Hanford illustrates the point. By the early 1960's, it became increasingly clear that the optimism expressed by Herbert Parker at the 1959 Joint Committee hearings was premature. The carbon steel tanks were being corroded at a faster rate than initially anticipated. Thus, a decision was made in 1965 to evaporate the waste solutions; the resulting salt cake not only would not leak but also would seal up any holes in the tank. Yet as the Natural Resources Defense Council noted in their petition for NRC licensing of ERDA's high level waste storage facilities:

> Eliminating the excess liquid has to a great extent also ended ERDA's ability to remove the waste from the tanks since as damp solids the waste can no longer be pumped hydraulically out of the tanks. Moreover, liquid cannot be reintroduced into many of the tanks to resuspend the waste since to do so would almost certainly result in substantial leaks to the ground.[37]

While the alternative of mining out the waste does exist, that technique is beset by a number of problems: a remote control system for mining would have to be developed; efforts would have to be made to reduce airborne releases; the material is difficult to deal with; there is no place to send the material once removed. Thus, while ERDA maintains that it has several viable alternatives to choose from, the record suggests that "the technological fix of solidification" may be a temporary one at best. It, too, has engendered problems for the future.

Consequences of Maintaining a Faith in a Technological Solution

The persistent faith in a technological fix has produced a myopic vision of the waste management problem. In theory, as well as in reality, the boundaries of the waste management "system" have been severely circumscribed. This constrained view of what must be considered in designing a waste mangement system has resulted in a number of significant distortions.

First, the waste management system is implicitly conceived of as being self-implementing. Those who believe in a technological fix strive to eliminate the human factor--an element which, it is generally held, can only produce noise. Yet, time and time again, persons interviewed stated that the weakest link in a waste management system will be the human one. Although many people believe that a human failure such as the one that took place in the 106T Tank leak at Hanford could happen again, there seems to have been little consideration by the AEC of what leads to such errors or how they might be forestalled in the future. One person suggested that du Pont be consulted to advise about the proper use of industrial relations (manipulation) because they seem to have been successful in this area in the past. But the only evidence offered for du Pont's success is that employees call their supervisors by their first names. Such a view of how to treat the "weakest link" in the system may not fully reflect AEC thinking. It most likely does reflect the degree of sustained consideration which the agency has given to this question.

A second distortion that has arisen because of faith in a technological fix is the very high discounting of factors which may be affected indirectly by the system. Complex decisionmaking is difficult. Rules of thumb have to be adopted to simplify problems that are seemingly intractable because of significant gaps in the knowledge base. Judgments have to be made about which factors to consider and which others to ignore.[38] Decisionmakers who view a problem through the rosy lens of a technological fix have made, and are likely to make in the future, their judgments in a particular way. Factors associated with technology's primary capacity such as economic growth, safety, efficiency, and perhaps even environmental consequences are given weight; factors associated with technology's indirect effects such as the impact on the social system or its implications for civil liberties are highly discounted.

Ignoring such indirect effects of course, might be eminently sensible if there were basis for believing that indirect effects are, in fact, negligible. Unfortunately, the issue was never faced by the AEC. For believing in a technological fix predisposes those decisionmakers to accept as negligible what is, in fact, really problematical. Such acceptance is facilitated because secondary impacts are hard to quantify. They are not amenable to easy inclusion in a cost/benefit analysis. In essence, then, these indirect consequences of technology are often banished to a never-never land where they lanquish unheard and ill considered. If the history of other complex technological systems had not demonstrated that those secondary effects could be significant, concern about discounting them highly in designing a waste management system would be muted. However, the track record from the past does strongly argue that the strategy of a "conservative" design philosophy should be adopted in all aspects of the construction of a waste management system and not merely in the technological components.

Still another consequence of the belief in a technological fix was that it reenforced factors that reduced the incentive to devote scarce organizational resources to solving the waste problem. Had not the AEC's vision of the issue been conditioned by a belief in a technological fix, the cost considerations and the location of waste management at the end of the fuel cycle would not have had the impact they did in facilitating postponement of a vigorous attack on the problem. The influence of these factors is subtle but nonetheless real.

Consider first the question of cost. Compared to the cost of other parts of the fuel cycle and particularly to the capital cost of reactors, the cost of even an extraordinarily elaborate waste management system is quite low. In 1959, in hearings before the Joint Committee on Atomic Energy, the cost was estimated to be considerably less than a fraction of 1% of the total generation cost of electricity.[39] Fifteen years later, while the "costs are very much higher than previously had been assumed they are still not at the point where they have an adverse affect on comparative economics of nuclear versus fossil fuel."[40] Although precise figures cannot be given now, estimates place the capital costs of the system at considerably less than 1% of the total investment of 200 reactors and their associated fuel cycle facilities. According to one estimate, approximately 0.06 mills per kilowatt hour out of a total of 25.6 mills per kilowatt hour cost of electricity from nuclear power would go for waste management.[41]

Its perceived low cost combined with an optimistic view of what the solution to waste management entailed allowed policy makers to neglect that part of the fuel cycle while developing other parts. Efficient waste management could be bought only by imposing substantial costs at the point of electricity generation or reprocessing. It was more cost effective to optimize those parts of the system and to settle for suboptimization at the final waste management step. Thus, efficiency in waste management was never a primary goal, as was the efficiency in reactor operations, enrichment, or reprocessing. It is not a large step from not worrying about optimizing a portion of the system to worrying about it hardly at all.

That waste management represents the final step in the system has also undoubtedly influenced people's approach to the question. If the attitude prevails that a solution can be willed into being when it is required, then there is little incentive to pursue it vigorously in the meantime. Too many, more immediate tasks have to be accomplished. It is not uncommon for people to say even today that the waste management issue is exaggerated. After all, we are told, we do not have any reprocessing plants operating; therefore, we do not have a waste management problem.

However, the most serious consequence rising from a faith in a technological fix is that it provides a rationale for decoupling the question of waste from the rest of the nuclear power system. By definition, a technological fix implies that a bounded solution can be implemented, one that by design does not have effects outside the technological core of the system. It is an easy transition from believing that a waste management system will not have indirect social impacts to believing that it will not have any impact on the rest of the nuclear fuel cycle. Once that transition is made, it is again an easy step to fragment the question of waste from the rest of the nuclear power system.

Such fragmentation is hardly a rare phenomena; it is caused routinely by a number of conditions such as budgetary constraints or short time horizons. The isolation of the waste management issue, however, was clearly compounded by the belief in a technological fix that allowed organizational decision makers to adopt a simplified vision of what is required to solve the waste management problem. Although intimately associated with a number of elements in the fuel cycle, waste management was never treated as part of an integrated whole. As a result any attention that was given to waste management was wholly because of its intrinsic interest as a technological problem.

That appeal however was often very low. At the highest levels there were no commissioners particularly interested in the problems of waste management; with the exception of Commissioner Thompson, never in the history of the AEC did that area have a lead commissioner who championed its needs in the same manner that James Ramey pushed reactor development or as Glen Seaborg pushed physical research. For most of the commissioners, waste was simply unpleasant and unglamorous. For example, Dixie Lee Ray, according to two informants, would simply turn up her nose when the subject was mentioned in meetings.

Nor could the cause of waste management be sustained through the skillful use of internal politics by personnel at lower levels. For them to pursue the issue intensely hardly made much sense. Grand careers were made in reactor development where the organization's resources were committed not in waste disposal. Moreover waste management also seemed to lack the intellectual challenges that surrounded reactor research or high energy physics.

In short, because faith in a technological fix facilitated the fragmentation of waste management from the rest of the nuclear fuel cycle, waste management literally became a residual category. Authority, and therefore responsibility, was diffused throughout the organization. Only after considerable prodding from outsiders did the AEC take steps to reorganize its waste management program.[42] In 1970, the Division of Waste and Scrap Management was created; a year later a stronger Division of Waste Management and Transportation was formed. However, even that new organizational base did not lead to more favorable treatment. Budget allocations remained almost pitifully small.[43] (See Table 1.1) Waste management, as the ERDA Task Force on the Nuclear Fuel Cycle correctly observed, remained neglected.[44]

In recent years, the failure of fragmentation has been made clear. Nuclear industry spokesmen complain about the uncertainties of the back end of the fuel cycle that were caused by the AEC's developing the different elements sequentially rather than having integrated them into a whole. Nuclear critics refuse to accept the AEC's word that technological solutions are at hand. In their minds, it is not optimism but blind unthinking faith which underlies the AEC's and now ERDA's arguments that we need not halt nuclear development until a "solution" to the waste problem has been found. Thus it seems that past attempts to simplify the problem by focusing on the technological side alone only have led to greater complications in the present.

Lessons to Be Learned

While the thrust of these arguments has been critical of the way waste management policy has been conceptualized, they should not be interpreted as an effort to blame individuals for actions they have taken in the past. Pointing the finger or passing out black hats is hardly a productive endeavor in the best of circumstances; but in this case recriminations are even more unwarranted than in most.

The failures of vision which plague waste management decision making are deeply rooted in the American approach to technological development. Alexis de Tocqueville for example, in the late 1830's remarked on how

	FY 1961	FY 1962	FY 1963	FY 1964	FY 1965	FY 1966	FY 1967	FY 1968	FY 1969	FY 1970	Cum. Through FY 1970
Nuclear Materials Program											
A. R&D Costs	$ 0.5	$ 1.1	$ 1.4	$ 1.5	$ 1.8	$ 1.4	$ 1.3	$ 1.7	$ 1.8	$ 2.0	$ 14.5
B. All Other Operating Costs	3.3	3.3	3.3	4.6	4.3	5.7	7.8	13.7	17.3	18.5	81.8
C. Plant and Capital Equipment Obligations	1.9	0.4	5.0	4.1	5.6	10.8	9.5	2.1	8.7	7.5	55.6
Subtotal Nuclear Materials Program	$ 5.7	$ 4.8	$ 9.7	$ 10.2	$ 11.7	$ 17.9	$ 18.6	$ 17.5	$ 27.8	$ 28.0	$ 151.9
Reactor Development Program											
A. R&D Costs	$ 3.5	$ 3.2	$ 3.1	$ 3.0	$ 3.8	$ 3.5	$ 2.7	$ 2.5	$ 2.9	$ 2.8	$ 30.8
B. All Other Operating Costs	--	0.8	0.3	--	--	--	--	--	--	--	1.1
Subtotal Reactor Development Program	$ 3.5	$ 4.0	$ 3.4	$ 3.0	$ 3.8	$ 3.5	$ 2.7	$ 2.5	$ 2.9	$ 2.8	$ 31.9
Waste Management Program											
A. R&D Costs	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --
B. All Other Operating Costs	--	--	--	--	--	--	--	--	--	--	--
C. Plant and Capital Equipment Obligations	--	--	--	--	--	--	--	--	--	--	--
Subtotal Waste Management Program	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --
Fuel Cycle R&D Program											
Waste Management (Commercial)											
A. Operating (All R&D) Costs	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --
B. Plant and Capital Equipment Obligations	--	--	--	--	--	--	--	--	--	--	--
Subtotal Fuel Cycle R&D Program	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --
Weapons Materials Production											
A. Operating (R&D) Costs	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --
B. Operating (Other) Costs	--	--	--	--	--	--	--	--	--	--	--
C. Plant and Capital Equipment Obligations	--	--	--	--	--	--	--	--	--	--	--
Subtotal Weapons Materials Production	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ --
TOTALS											
A. R&D Costs	$ 4.0	$ 4.3	$ 4.5	$ 4.5	$ 5.6	$ 4.7	$ 4.0	$ 4.2	$ 4.7	$ 4.8	$ 45.3
B. All Other Operating Costs	3.3	4.1	3.6	4.5	4.3	5.7	7.8	13.7	17.3	18.5	82.9
C. Plant and Capital Equipment Obligations	1.9	0.4	5.0	4.1	5.6	10.8	9.5	2.1	8.7	7.5	55.6
GRAND TOTAL	$ 9.2	$ 8.8	$ 13.1	$ 13.2	$ 15.5	$ 21.2	$ 21.3	$ 20.0	$ 30.7	$ 30.8	$ 183.8

Table 1.1

Summary of Waste Management Funding (Millions)

	FY 1971	FY 1972	FY 1973	FY 1974	FY 1975	FY 1976	Transition Quarter	FY 1977	FY 1971-FY 1977
Nuclear Materials Program									
A. R&D Costs	$ 1.5	$ 1.8	$ 1.6	$ 1.8	$ --	$ --	$ --	$ --	$ 6.7
B. All Other Operating Costs	20.3	21.9	24.3	33.7	--	--	--	--	100.2
C. Plant and Capital Equipment Obligations	9.9	24.0	11.5	44.4	--	--	--	--	89.8
Subtotal Nuclear Materials Program	$ 31.7	$ 47.7	$ 37.4	$ 79.9	$ --	$ --	$ --	$ --	$ 196.7
Reactor Development Program									
A. R&D Costs	$ 1.7	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ 1.7
B. All Other Operating Costs	--	--	--	--	--	--	--	--	--
Subtotal Reactor Development Program	$ 1.7	$ --	$ --	$ --	$ --	$ --	$ --	$ --	$ 1.7
Waste Management Program									
A. R&D Costs	$ --	$ 4.4	$ 5.0	$ 9.9	$ --	$ --	$ --	$ --	$ 19.3
B. All Other Operating Costs	--	1.3	1.6	2.3	--	--	--	--	5.2
C. Plant and Capital Equipment Obligations	--	1.6	0.2	2.6	--	--	--	--	4.4
Subtotal Waste Management Program	$ --	$ 7.3	$ 6.8	$ 14.8	$ --	$ --	$ --	$ --	$ 28.9
Fuel Cycle R&D Program									
Waste Management (Commercial)									
A. Operating (All R&D) Costs	$ --	$ --	$ --	$ --	$ 9.4	$ 11.9	$ 3.4	$ 60.0	$ 84.7
B. Plant and Capital Equipment Obligations	--	--	--	--	0.5	0.6	0.2	5.8	7.1
Subtotal Fuel Cycle R&D Program	$ --	$ --	$ --	$ --	$ 9.9	$ 12.5	$ 3.6	$ 65.8	$ 91.8
Weapons Materials Production									
A. Operating (R&D) Costs	$ --	$ --	$ --	$ --	$ 11.5	$ 16.8	$ 4.9	$ 28.1	$ 61.3
B. Operating (Other) Costs	--	--	--	--	42.4	52.7	14.5	61.7	178.3
C. Plant and Capitl Equipment Obligations	--	--	--	--	31.7	83.6	24.2	119.9	219.4
Subtotal Weapons Materials Production	$ --	$ --	$ --	$ --	$ 85.6	$ 153.1	$ 43.6	$ 211.7	$ 459.0
TOTALS									
A. R&D Costs	$ 3.2	$ 6.2	$ 6.6	$ 11.7	$ 20.9	$ 28.7	$ 8.3	$ 88.1	$ 173.7
B. All Other Operating Costs	20.3	23.2	25.9	36.0	42.4	52.7	14.5	63.7	278.7
C. Plant and Capital Equipment Obligations	9.9	25.6	11.7	47.0	32.2	84.2	24.4	125.7	360.7
GRAND TOTAL	$ 33.4	$ 55.0	$ 44.2	$ 94.7	$ 95.5	$ 165.6	$ 47.2	$ 277.5	$ 813.1

Table 1.1 (continued)

eagerly Americans adopted new innovations. That faith in the technological progress has remained an integral part of the American character. It is hard to fault an agency for being in tune with that fundamental spirit.

However, in recent years evidence has accumulated that calls into question the seductive nature of the technological fix. Nuclear agencies ought to reassess their approach to problem solving. That reconsideration will, unfortunately, be painful. Long held traditions and patterns of behavior rarely are altered easily. There are costs--perhaps heavy ones--to be paid. However, it is hard to imagine that any other course of action can yield positive results in the long run. Continued faith in a mythical easy technological fix can only push the nuclear agencies further outside the bounds of reality.

The difficulty of shifting the way the waste problem is conceptualized can be eased if the ERDA and NRC were to open themselves to interested outsiders particularly to those who may hold different views about which courses of action to adopt. Past agency practices of virtually ignoring critical outsiders such as the National Academy in the case of the Savannah River Bedrock Project or the Government Accounting Office in the case of waste management production facilities need to be reconsidered. Broad participation and decision making does not guarantee good outcomes, but it can spotlight flawed conceptualization of the problem. Had such institutionalized criticism existed in the past, the AEC might not have held to its faith in a technological fix as long as it did.

Notes to Chapter 1

1. See, for example, the GAO report, Observations Concerning the Management of High Level Radioactive Waste Material, May 29, 1968. (1968 GAO Report)
2. GAO report, Isolating High-Level Waste From the Environment: Achievements, Problems, and Uncertainties, December 18, 1974, pg. 8. (1974 GAO Report).
3. Figure is taken from WASH-1202 (73) Plan for the Management of AEC Generated Radioactive Wastes, p. 42.
4. See ERDA-1538, Waste Management Operations at Hanford Reservation, Vol. I, p. III. 2-2 and Vol. I, p. II.1-c.
5. 1974 GAO Report, p. 13.
6. Ibid., p. 13.
7. NAS/NRC Report: The Disposal of Radioactive Waste On Land, Sept. 1957, p. 4. (1957 NAS Report).
8. NAS/NRC 1961 update of 1957 NAS report, as quoted in Draft WASH-1538.
9. See R. L. Bradshaw, W. C. McClain, and J. O. Blomeke, Radioative Waste Repository in Salt: Preliminary Cost Estimates and Comparison of Alternative Sites, ORNL-CF-69-6-69 (June, 1969); and Bradshaw and McClain, eds., Project Salt Vault: Demonstration of the Disposal of High Activity Solidified Wastes in Underground Salt Mines, ORNL-4555, April 1971.
10. Interview with Frank Pittman and Alex Perge.

11. See AEC 180/88 Siting of Commercial Fuel Reprocessing Plants and Related Waste Management Facilities, June 17, 1970.

12. See AEC 180/87 Solid Radioactive Wastes: Long Term Storage in Central Kansas Salt Mine, June 12, 1970.

13. AEC 180/87, p. 4, 16.

14. See AEC Authorizing Legislation Fiscal Year 1972, Hearings before the JCAE, Part 3, 1971, pp. 1349-1378.

15. See AEC Authorizing Legislation for Fiscal Year 1972, Project 72-3.

16. See SECY-2271, High Level Waste Management, February 2, 1972.

17. See Memorandum, W.B. McCool to R.E. Hollingsworth, "Program Review: High Level Waste Management," February 7, 1972.

18. See SECY-2333, High Level Waste Management, February 24, 1972.

19. See SECY 74-222, Policies for Management of Commercial High Level Waste, November 16, 1973.

20. EPA response to DRAFT WASH-1539, dated Nov. 15, 1974 (unpublished).

21. Letter from R. C. Seamans, Jr. to the Hon. John O. Pastore; April 9, 1975.

22. c.f. R.K. Merton, Social Theory And Social Structure, (revised edition: Free Press, N.Y., 1968) for an exploration of this idea first advanced by Veblen.

23. Industrial Radioactive Waste Disposal, hearings before the JCAE, 1959, pp. 992-3. (1959 JCAE hearings).

24. Speech by Frank Pittman to the ANS, November 16, 1972, reprinted in AEC press release S-18-72, p.2.

25. See Jacques Ellul, The Technological Society, Vintage, N.Y., 1964.

26. 1957 NAS Report, p. 16, 17.

27. Ibid., p. 34.

28. Ibid., p. 3.

29. Ibid., p. 6.

30. 1959 JCAE hearings, p. 9.

31. Ibid., p. 11.

32. Ibid., p. 10.

33. Ibid., p. 165.

34. AEC Report on the Investigation of the 106T Tank Leak at the Hanford Reservation, June, 1973, pp. 51-57. (106T Report).

35. WASH-1539, p. III,2-3.

36. 106T Report, p. 6.

37. NRDC "Memorandum of Points and Authorities in Support of the Nuclear Regulatory Commission Licensing of the Energy Research and Development Administration's High-Level Waste Storage Facilities under the Energy Reorganization Act of 1974," p. 18.

38. See Cyert and March, Behavioral Theory of a Firm, McGraw-Hill, N.Y., 1964.

39. 1959 JCAE hearings, p. 2352.

40. ERDA-33 Nuclear Fuel Cycle, March 1975, p. 46.

41. Ibid., Chart 10.

42. See 1968 GAO Report, pp. 18-20.

43. Figures supplied by Alex Perge, ERDA's Division of Nuclear Fuel Cycle and Production.

44. ERDA-33, Chart 6.

CHAPTER 2

OPTIONS FOR WASTE MANAGEMENT--CRITERIA FOR CHOICE

Introduction

There is a consensus that the single over-riding criterion for selecting a method for the disposal of high-level wastes should be their isolation from the biosphere. This should be ensured for a long enough time and to a sufficient degree so that they present no significant hazard to life over their lifetimes. It is much more difficult to get consensus on the definitions of "long enough," "sufficient degree," and "no significant hazard." The very long half-lives involved raise serious questions as to our ability to predict geological or material stability over the necessary storage times. More significantly, our inability to predict relevant social or political factors over times of even hundreds of years precludes any estimation of either the impact of a containment failure or the conditions that might result in an accidental or deliberate breach of the system.

A further complication is the presence of very large quantities of short-lived beta and gamma emitters, primarily fission products, that present an enormous short-term hazard and make handling of the wastes difficult.

Whatever method for waste management is selected will necessarily have a non-zero risk of accident or sabotage, and thus a finite chance of large damage and loss of life over the short term. A method for disposal that ensures complete long-term security will not be acceptable if the short-term risks are excessive. But again, this raises the question as to what constitutes an acceptable short-term risk, and what are the benefits to be gained by assuming this risk for the sake of long-term security against containment or isolation failure.

Ethical and Moral Concerns

There are, in fact, four considerations in deciding upon an acceptable method for the disposal of nuclear wastes: long-term safety, short-term safety, operational safety, and cost. But none of these are quantifiable. It may be possible to judge risk and price, although the uncertainties involved are large enough so that this may be questionable. These are normative judgments that must ultimately be made by society through the political process.

Crucial to this procedure will be the ranking of concerns. If cost or operational safety are the dominant factors in the future as they have been in the past, then there is little or no likelihood that space disposal operations will ever be seriously considered. But, as discussed in detail further on in this section, there is strong empirical evidence that the general public ranks long-term safety ahead of both short-term safety and cost as criteria for selecting a waste disposal method. Although nuclear technologists and, to a lesser extent, public utility employees did not agree with this ranking, placing cost first followed by short-term and then long-term safety, we do not believe that this attitude will remain unchanged. Indeed, a great deal of the present controversy over the disposal of nuclear wastes arised from this difference between the elites and the public.

This public attitude would appear to reflect the predominance of ethical and moral concerns over economic ones. But ethics and morals are prehaps the ultimate externality, in that there is no way at all that they can be brought in to a cost-benefit analysis. That these concerns appear to be somewhat vague and formless to the nuclear industry is partially a reflection of this non-quantifiability, and partially due to the great difficulty of formulating the ethical and moral basis for dealing with the far future.

In his widely-quoted article, Alvin Weinberg characterized the development of fission power as a "Faustian bargain," with eternal vigilance being the price extracted for the acquisition of a "nearly inexhaustible" source of energy.[1] His conclusion was that the required vigilance was not too great a price to pay. But this is one of the normative judgments that society must be free to make. Indeed, Weinberg's discussion raises two crucial ethical issues. Future generations would be required to maintain this vigil, and the associated institutions, without choice and without deriving any of the benefits. The ethical basis for the present assuming the benefits while exporting the risks and associated costs to the future is less than secure. All forms of cost-benefit or risk-benefit analysis necessarily assume that goods and bads will accrue to the same population, at least in the generic sense. Furthermore, the use of mathematical tools such as discount rates for dealing with the costs and benefits to the future can extend at most a few decades.

The second ethical problem raised is that of greatly increasing the uncertainty experienced by future generations. Hannah Arendt[2] has pointed out that the future is by definition uncertain, that unpredictability of result is a necessary consequence of any action. In this regard, we may hold that the degree of uncertainty is certainly smaller for the near future than for the far. But ethical behavior does not come in degrees. If it could be stated with certainty that the techniques and institutions for waste management could be constructed so that they would be reliable over the many thousands of years required, if it could be guaranteed that future generations would be equipped to deal with possible failures and maintain the sites adequately, then cost-effectiveness might be an appropriate criterion. It is, however, not ethically or morally sound to act as if this were so and deny the role of social and political uncertainty. Nor is it ethical to coerce the behavior of the future by requiring that they guarantee their own social and political stability or else bear the consequences.

There is a small body of literature on this problem. Smith[3] re-examined the possibility of using risk-benefit analysis and came again to the conclusion that no finite social discount rate can be used, and that any attempt to perform quantitative risk evaluations into the far future is pre-ordained to failure. Even if the total releases of radionuclides could be predicted with a fair amount of certainty, it is not possible to determine the population distribution, and therefore the total dose received, or the possibility or efficacy of mitigating measures. Moreover, it is not possible to determine how a life in the future would be valued.

Attempts to deal with the future within the structure of economics have similarly had little success. Kenneth Arrow has stated that the ethical basis for free-market economics in the first place is full access to all available information.[4] However, this assumes that the information is available and that the purchaser can make a choice. As the future can not make a choice and may not have information in any case, the ethical foundation for using economics at all is not present, and the use of a discount rate at all is highly dubious. Georgescu-Roegen[5] also points out the futility of trying to apply a discount rate, but goes further to show that, without even attempting to discount, ethical behavior requires that all affected generations have a voice in setting the price of the risk. Unless a prohibitively large and logically unjustified discount rate is used for calculating voting power, the present will have such a small share of the vote as to deny it any basis for unilateral action. Both of these outstanding economists agree that their discipline provides us with no useful tools for dealing with these issues.

Golding[6] and Callahan[7] have discussed the ethical and value problems in terms of our "obligation" to future generations. Golding defines this obligation in terms of a "moral community" that merits our consideration because it shares with us certain social ideals. As members of a common moral community, the future then has certain shared rights and can make certain presumptive claims upon the present. This in turn entails an obligation to plan for the "good" of the future, to provide for them. Yet, as our knowledge of the distant future is quite imperfect, and the nature and outcome of these rights and claims unsure, the definition of the "good" of the future by the present in both arrogant and unwarranted. Perhaps our primary obligation, then, is <u>not</u> to plan for them at all.

In response to this argument, Callahan points out that Golding confines himself solely to positive planning, and that the obligation to avoid damaging the future has no time horizon. He argues for a set of ethical norms based on irreducible rights that derive not from the social organization of the future, but its humanity. The duty to preserve them from harm is an obligation based not on their social ideals, but their fundamental rights to survival and human dignity. Regardless of the intervening time, we should refrain "as far as possible" from jeopardizing these, taking into account the equally valid rights of the present.

Both of these authors implicitly assume that traditional ethical norms can be carried over continuously from dealing with our contemporaries to our descendants, and through them to the future. But, as Jonas[8] has pointed out, the maxims of traditional ethics are confined to a moral constituency comprised of the sharers of a common present and, at most, their immediate descendants. It is the immediate good or evil of an act that determines its moral and ethical content, and the long-term and possibly unforeseen consequences of those actions are to be left to providence.

Even the creation of irreversible consequences for the future could not be considered unethical. Every action we take has some irreversible consequent, and if the future has to provide for itself out of what it has been given, this is no more than was given to the present. It is only required that an action be well-intentioned and well-performed within the immediate context of knowledge and effect.

But Jonas further argues that the scale of possible impacts of modern technology has burst the framework of traditional ethics. Such bulwarks of morality as Fiat justitia, pereat mundus[9] cease to be applicable when the consequences of present action can result in the world perishing in fact, and not just in metaphor. He argues an axiomatic basis for our obligation to the distant future: that there ought to be a future at all and humans in it, is as undemonstrable as it is persuasive. What has changed is our ability to destroy the basis for all obligation, the existence of candidates for a moral order at all.

Ordering the Criteria

We therefore argue that there is a persuasive case for subordinating both operational and short-term risks to potential long-term risks, and that cost may be taken to be the least important of the criteria. Cost should be used not as a determining factor, but as a boundary condition to be satisfied by a method selected to minimize risk. Once such a method is selected, it is then to be examined to determine the social and economic costs. These are unlikely to be prohibitive for any of the methods currently being suggested, including space disposal.[10] If the costs are subsequently judged to be excessive, that decision will have to be justified. Affordability is a flexible social and political decision. In the absence of actually prohibitive costs, the question is what level of safety society is willing to pay for.

A similar argument is made for subordinating short-term and operational risks to long-term ones. The relatively immediate risks of waste disposal operations will at least be borne by the same population that derives benefits from the nuclear power that creates the wastes. The normative values of safety and benefit can be submitted to societal judgment; as with cost, the social and political guidelines are elastic and adjustable. Certainly there will be a desire to minimize present risks. If this entails the selection of a method whose long-term risks are higher, then risk is being exported to future generations who will derive no direct benefits and who have no voice in formulating the normative decision framework. The ethical and moral problem of justifying the exporting of risks to the future, or to others who do not participate in the benefitting society, may not be a resolvable one. Again, the minimum ethical criterion is that such decisions be made explicitly.

The primary criterion for ordering waste management options, is the minimization of long-term risks. If these could be precisely determined, waste management options could be easily ranked. But there are great technical and social uncertainties as to the integrity of waste containment over the long times that it must be maintained. An acceptable method for the disposal of high-level wastes must be proof against technical failures such as corrosion of materials and scientific failures such as overestimating the efficacy of natural barriers to migration as well as against geological changes, glaciers, and earthquakes. Few disposal methods can be confidently guaranteed to be permanent over the hundreds of thousands of years that isolation is needed; a more reasonable criterion is that, should the containment fail, the time to return the wastes to the environment is of the same order of magnitude as the time necessary for the toxicity to be reduced to a level at or below background radiation at a comparable site. The uncertainty associated with imperfections in present knowledge and the probabilistic nature of the frequency and severity of cataclysmic events can be somewhat compensated for by secondary barriers that provide for slow diffusion and return of the wastes.

Owing to the very long half-lives of even the short-lived components of the wastes when measured against social and political time scales, no guarantee of future ability to repair, clean up, or even recognize a breach of containment can be assumed. Our inability to predict social, cultural, or political futures also implies that an acceptable disposal method must be secure not only against accident or failure, but also against both inadvertent and deliberate but uninformed entry. Given the insatiable curiosity of intelligent life, the more attention a site attracts, the more likely it is to be breached. To one who can not read or translate it, a warning sign is more likely to initiate such activity than to prevent it.

The amount of radioactivity in the waste as a function of time and technical and scientific estimates of the probability of failures can be used to generate a set of numbers that express the long-term risk as the probable release in any given year. But whether the case chosen is average release or worst-case, these data must be converted via toxicity, mobility, and population distributions to yield even a rough measure of social impact. Such numbers are too imperfect and incomplete in the face of social, technical, and geologic uncertainties to provide useful guidelines for the evaluation of alternative disposal methods. What is suggested below is a method for extending the risk evaluations into a set of criteria that reflect not only technical paths for returning the wastes to the environment, but also the possibility of active intervention by more or less intelligent beings. The reasoning presented here has informed both our technical and social impact analysis.

Technical Irreversibility

Technical irreversibility is defined as the degree to which emplaced wastes are resistant to recovery or release either by accident or by the deliberate application of technology. Its significance as a criterion is that the more irreversible a waste disposal method is, the more confident we may be that the wastes will remain isolated in the face of social, technical, and geologic uncertainties. If technical irreversibility is high, then neither cataclysmic natural events nor the activities of intelligent and technologically adept beings can readily return the wastes to the environment. Retrievable surface storage, for example, is highly reversible: vulnerable to accidents and easily accessible for recovery. Ejection into deep space is almost completely irreversible. Melting the wastes into a solid rock matrix would be highly irreversible: a geologic event that would result in large releases of toxic radionuclides would be very improbable; the application of fairly advanced and sophisticated mining technology would be required to deliberately re-extract them from the rock.

Technical irreversibility, then, is defined both socially and physically. It does not correlate precisely with scientifically defined notions of irreversibility. Irreversibility as defined by the second law of thermodynamics is based on the difficulty of restoring an initial situation in the face of statistical probabilities. The presence of intelligence, however, allows the creation of improbable circumstances. Reversibility may be expensive, but it is not in principle impossible.[11] Irreversibility can also be expressed mechanically, as with a ball rolling down a hill in the middle of a flat plain. The application of a little intelligence, and possibly a little energy as well, can easily restore the ball to the top of the hill.

There are parallel examples of social irreversibility. It is much easier to create a bureaucracy than to destroy it. Increases in the perceived quality of our lives are not readily foregone. An example of almost purely social irreversibility that is more to the point here is the fabulous pirate practice of burying a treasure in a remote or obscure location and then killing those who know of it. The mechanical act of retrieving the treasure is very simple, and quite reversible. But to the extent that accidental discovery is highly unlikely and that a deliberate, but unguided, search has a very low probability of success, this emplacement is very irreversible.

The purpose of imposing irreversibility as a criterion is to provide some degree of security against breaching of containment and failure of isolation in the face of unknown social, political, and cultural developments, to provide the greatest possible security against their release or misuse by an agent not equipped to recognize or cope with the dangers. Although stability against geological change is necessary to provide the desired degree of isolation and to prevent accidental release, the degree of reversibility also depends on the amount of attention that might be drawn to the site by geological features or identifiable artifacts. Intelligent life is notoriously incautious in indulging its curiosity. Construction of a large concrete mausoleum on a remote mountain top may be mechanically quite irreversible, but the attention it would draw would almost guarantee that concerted efforts would be made to breach it by intelligent, but uninformed life. On social ground, such a method is held to be quite reversible. Additional irreversibility cannot be provided by warning messages, symbols, or labels. We cannot assume that even a society that has the technology to undo other irreversible storage will know enough about radioactivity to proceed cautiously, or that they will be able to decipher a message they cannot read. Indeed, the presence of such an indecipherable message would only arouse additional interest. "Interesting" geological formations such as salt domes are equally likely to draw attention. The society that drills into them may know nothing of radiological hazards, but still be sufficiently advanced technologically and scientifically to be curious about the formation itself and its possible contents.

It should be kept in mind that technical irreversibility is meant to provide a criterion for choice and not to preempt it. Complete irreversibility that precludes all possibility of recovery of the wastes may not be the most desirable outcome. It can be argued that our obligation to the future extends to the preservation of options as well as the prevention of harm, that we have an obligation to try to avoid irreversible consequences of our actions. It may then be considered most desirable to dispose of the wastes by a method roughly as irreversible as the dispersal of uranium in present ores.[15] This would at least partially correct the irreversible depletion of natural supplies of fissionable material. The provision of an artificial ore bed is intended to make these materials accessible only to those who understand what they are mining and why. In that regard, the artificial beds could be somewhat more secure against accidental mining than natural beds have been if care is taken to make sure that the wastes are not co-located with other desirable minerals. A criterion for site location that aids irreversibility is that it be as uninteresting as possible, and so draw no attention for other reasons.

Table 2.1 is a preliminary classification of several waste disposal methods mentioned in the current literature according to the degree of technical irreversibility possessed by each. In most cases, the net irreversibility is derived from consideration of both technical and social factors. The categorization is deliberately broad, as a more precise distinction would require more detailed analysis of the several options and is, in any case, limited by technical and social uncertainty as discussed previously. What is not indicated on this table is that many of the suggested waste disposal methods could be made more or less irreversible by a judicious alteration of present plans to provide additional technical or social barriers to prevent breaches of the containment and isolation. For example, emplacement in geological formations would be more irreversible if chemical means could be found to immobilize the wastes against uptake into biological systems, since such uptake can both increase waste mobility and provide for subsequent reconcentration of the wastes in the food chain. Disposal on the ocean bottom would be more irreversible if the location of the canisters is not known and they are randomly placed so that a deliberate and informed search would be necessary to recover them in significant numbers.

Technical irreversibility, then, is seen to be determined largely by the size and sophistication of the technology or natural mechanism that would be necessary to return the wastes to the biosphere in quantities or at rates that would be radiologically significant. It tends to correlate fairly well with the degree of scientific and technical aptitude that would be required for deliberate waste recovery by a society of intelligent beings, and with the size and cost of the necessary effort. The greater the degree of technical irreversibility, the more confident we can be that, if the waste disposal technology works as advertised, any failure of isolation and containment will occur only through the intervention of those fully capable of understanding the risks involved.

Disposal Method	Physical Irreversibility	Social Irreversibility	Net Technical Irreversibility
Retrievable surface storage	Moderately low for above ground convection cooled casks to very low for water-cooled complexes	Very low	Very low
Mined salt caverns	Low to very low depending on proximity of ground water	Low for salt domes to moderate for bedded salt	Low
Sandstone caverns	Moderate	Low to moderate	Moderate
Space: Earth orbit	Moderate to moderately high	Moderately high	Moderate to moderately high
Deep rock melt	Moderate to high depending on formation and water	High	High
Space: very high Earth orbit	Very high	Very high	Very high
Space: Solar Escape	Complete	Complete	Complete

Table 2.1

Waste Disposal Systems Classified by Irreversibility

Multiplicity

Yet another set of factors must be considered--multiplicity of sites and diversity of options.[15] These provide further measures against error and uncertainty. In this regard, the value of increased multiplicity must be carefully examined to ensure that it will reduce the probability of damage and not increase it. If the number of sites is increased, the probability that one of them will fail or be accidentally breached may also increase. In that case, the potential damage that could be done by a release should be reduced to compensate. Clearly, the balance between these factors depends upon whether the amount of material contained at a site is judged to present a small or an enormous hazard to life, and selecting an appropriate operating point is at least partially a normative decision.

For example, the irreversibility of many types of terrestrial geological disposal methods could be increased by making the number of canisters very large and the potential risk due to the breach of any single canister relatively small. The technical measure can then be augmented by randomly emplacing the canisters in unrecorded locations, making deliberate recovery more difficult. This may make the accidental discovery of a single canister more probable. If so, the increase in probability of discovery must be balanced against the lower radionuclide inventory to see whether analysis bears out the intuitive reasoning that this strategy would increase net irreversibility against a wide range of geological and social factors. An alternate approach would be to collect many years production of waste into a single giant container and then to emplace this so deeply and with such redundant barriers that any breach seems highly improbable. This mechanical approach to increasing irreversibility significantly increases the probable consequences of a release. It is our contention that this provides less net irreversibility in the face of uncertainties as to the nature and probability of potential catastrophic events. Again, it would be useful if this intuitive response could be supported by more detailed analysis.

Multiplicity of sites does not, of course, provide any security against fundamental conceptual or design errors. It does help to minimize the consequences of such errors if the failures are random and widely spaced both temporally and physically, or if gross errors are most likely to occur soon enough so that a fair guarantee of ability to take remedial action can be given. But if confidence in the performance of a single site is high, multiplicity does not necessarily provide an advantage on technical grounds.

The primary advantage of site multiplicity is the minimization of the consequences of errors and uncertainties in social judgments, in minimizing the potential consequences of the deliberate or inadvertant action of intelligent life. One aspect of this is damage limitation. If the opening of a single site causes minimal harm, and if the discovery of one site does not automatically provide the key to uncovering other sites by other than informed and sophisticated actors, catastrophic releases are unlikely to occur. Furthermore, this would provide at least the time for effects to be noted and for the proximate, if not the ultimate, cause to be realized. We are also unable to predict the distribution and habits of future populations. Site multiplicity would tend to reduce the possibility of severe accidents. Our more complete uncertainty as to future behavior, as opposed to future geology, leads us to conclude that provisions for damage limitation carry more weight when considering social uncertainties.

Increased site multiplicity is not identical to increased technical irreversibility, although it tends to correlate with it for many waste disposal methods. In the case of some, such as retrievable surface storage, the two criteria are nearly independent of one another. For some, such as space disposal, multiplicity will affect only the immediate risk.[16] In other cases, it can be used to separate two methods that have roughly equal irreversibility.

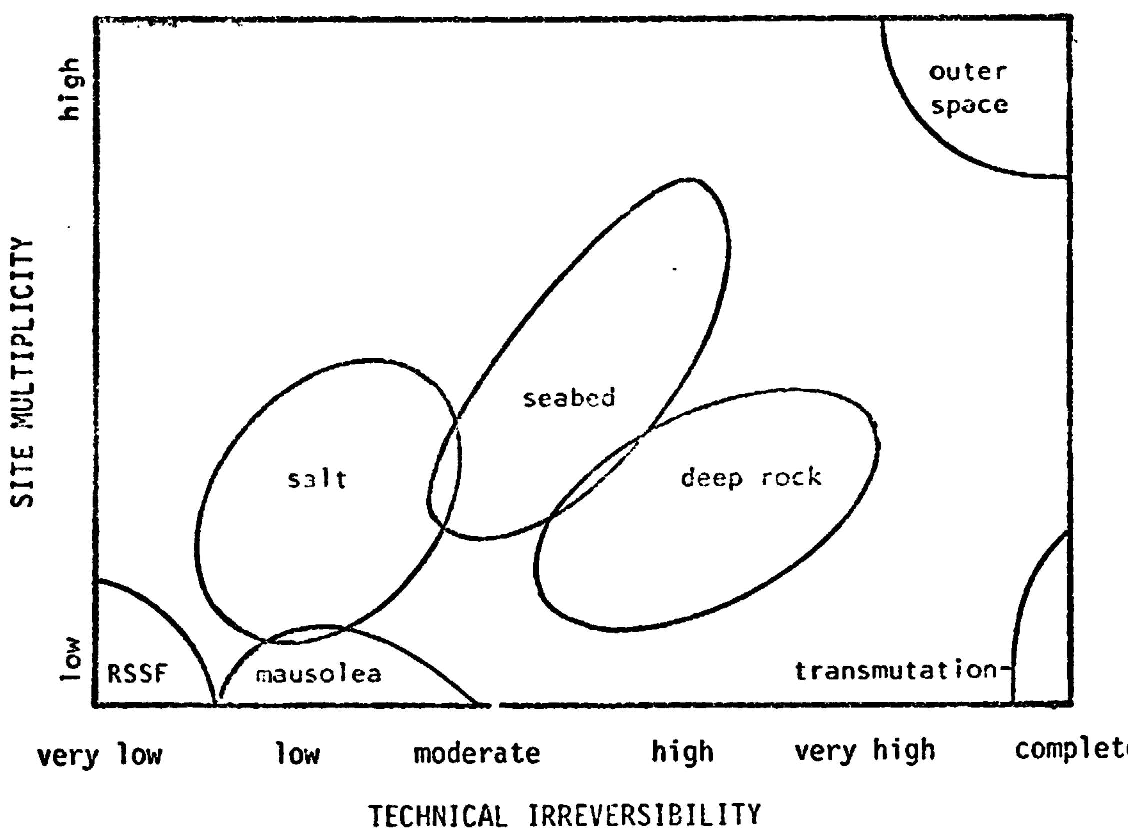
Figure 2.1 locates a number of waste disposal options on a two-dimensional plot that treats the technical irreversibility and site multiplicity as independent criteria. In doing so, we explicitly do not attempt to assign relative weights to them. It must be emphasized also that this is a qualitative map, and that not only the absolute, but possible also the relative location of any option is a matter of informed judgment. It is not only difficult but unwise to try and localize any method too narrowly. Even if the axes could be precisely and quantitatively labeled, inherent uncertainties in predicting the future would limit our ability to pin down any method precisely.

Applying the Criteria

The previous discussion can be graphically interpreted by saying that the further into the upper right hand corner of Fig. 2.1 a method lies, the greater the reduction of potential future risks in the face of technical, physical, and social uncertainties. Put conversely, the more confident we are about social and physical stability over the time scale during which the wastes must be kept contained and isolated, the closer to the lower left corner an acceptable method will lie.

Figure 2.1

WASTE DISPOSAL METHODS



PREFACE

This report is the result of a study funded by the National Aeronautics and Space Administration through the Ames Research Center to . . the feasibility and implications of a hypothetical decision to d[illegible] of long-lived high-level nuclear wastes, or some p[illegible]ion of these wastes, in outer space. It is important at the outset to delineate the boundaries of the study and to clearly state the premises that were stipulated and distinguish them from those areas that were more thoroughly explored.

The focus of the research has been on the social and political implications of a decision to implement the space disposal idea, and on the various social and political structures that would be associated with it. The technical work that has been done (primarily under an independent, but associated intergovernmental personnel agreement with Dr. Gene I. Rochlin) was oriented primarily towards setting out the boundaries of a model for the nuclear industry and of the associated fuel cycle services so that accurate estimates for high-level waste quantities and characterization could be made. Owing to the large number of possible decisions that might be taken regarding the post-reprocessing treatment of population as that surrounding the present launch site at Cape Kennedy would require far more in time and resources than could possibly have been allotted to this study. Moreover, as have often been stated, the social or political scientist works in a real world situation that is not subject to ready abstraction. The impact on any specific population is, in fact, specific to that population in its exact situation. More generalized rules can be abstracted, but they must be applied with great caution.

We do not attempt to speak with precision about that which we were unable to explore in detail. The level of analysis, therefore, varies from section to section within this report. With regard to extant technologies and past and present policy apparatus, some detailed and fairly specific comments could be made. But with regard to future decisions and future social and political impacts, the analysis is generic, not specific, and should be applied with some caution. A careful analytic group is strictly a non-prophet organization. What has been done is not to attempt to predict outcomes or future, but to sketch out what experience and analysis have taught us about the responses of and impact on both selected and general populations under similar circumstances.

The report is organized as follows. In Part I we outline the background political and technical data that are needed for performing the impact analysis. Both in a historical policy context and in terms of the present and likely future development of nuclear power technology and waste management, we outline the preconditions that would have to be met for the space disposal option to be given serious consideration.

In Part II we describe the potential role of the space shuttle program in the management and disposal of high-level wastes. This

INTRODUCTION TO PART I

In Part I of this study, we introduce the preconditions for the technical and political decisions that would have to be made in order for the space disposal program to be given even serious consideration as an option on the same footing as such current plans as disposal in salt beds. This material supplies the necessary background for the discussion in Part II of this report of the potential role of the NASA shuttle program in nuclear waste disposal, and the analysis of not only the technical and scientific, but the social and political milieu that would be required for a decision to move towards implementation.

Chapter 1 focuses on the past history of radioactive waste management in the United States, for its is important in setting up the social and political context to understand how and why it came to be that nuclear waste disposal remained an unresolved problem as long as it did. Secondly, one should be cognizant that future decisions will not and cannot be taken in an atmosphere free of the clouds of old battles over wastes. No waste disposal program, including this one, can ever operate with the blank slate of ten years ago.

Chapter 2 sets out the ethical and moral concerns over long-lived toxic radionuclides that form the fundamental motivation for consideration of such expensive and high-technology disposal programs as transmutation or space disposal. For, were it not for our concern over the future and their well-being, it is clear that waste disposal would not be considered a major problem. Getting the wastes out of the biosphere for our lifetimes would be no great technical feat. Even for the lifetimes of our children, there are many ways to emplace the wastes to preserve them from harm. But over the very long lifetimes of the transuranic isotopes as potential hazard, our uncertainty as to geology, culture, social and political development, and demography raise to a high level our uncertainty about the future's ability to recognize an untoward event, let alone to reduce its consequences.

Chapters 3 and 4 address the technical preconditions for space to become a chosen option. In Chapter 3, we discuss the growth of the nuclear power industry and its associated wastes, as well as the supporting fuel cycle facilities that will be needed. Within this context, we examine the several ways of processing spent fuel that would reduce the waste masses to quantities manageable by a hypothetical space disposal program. In Chapter 4, this information is used to derive a set of technical criteria for efficiency of fuel cycle operation that would allow the space program to respond to the concerns raised in Chapters 1 and 2. For, unless there is a major reduction in the terrestrial inventory of transuranic isotopes, and particularly the isotopes of plutonium, it would simply not make sense to invest the resources that would be required, technically, economically, politically, and socially, to make the space disposal program a reality.

The two criteria measure, in a crude way, reduction of risk over increasing time and the attendant increase in uncertainty. Using Fig. III-1 as an illustrative device once again, this is equivalent to asserting that there is an effective time scale measured diagonally from the lower left (reversible single site) to the upper right (maximum irreversibility, high multiplicity). If this is the case, we may sketch sets of indifference curves, loci of equivalent preference for acceptability of waste management options. In the absence of multiplicity as a criterion, these would simply reflect similar degrees of technical irreversibility.

When both criteria are considered, we suggest that an appropriate result of increasing site multiplicity would be the acceptance of a somewhat less irreversible disposal method, since multiplicity reduces the consequences of error. It is therefore suggestive to represent any lines of equal preference as arcs upon the diagram, reflecting the joint effects of the two criteria reducing risk. As with the location of any particular disposal method, these will be somewhat fuzzily defined.

Where Does Space Disposal Fit In?

As may be seen from examining either Table 2.1 or Fig. 2.1, space disposal is an "extreme" method when judged according to our two criteria. It is completely and totally irreversible if the solar escape mission is chosen. As was argued above, it is not clear that such complete irreversibility would or will be the choice made by society. It is still within the bounds of possibility that a high earth orbit would be selected, as this provides what amounts to retrievable storage, and retrievable only to a highly technologized society. But the stability of these orbits would have to be carefully analyzed.

Returning to our previous assumption that solar escape would in fact be the chosen mission, it is clear that space disposal presents the greatest degree of long-term protection against social and terrestrial uncertainties of any disposal method. This is not a surprising result, nor was it meant to be. The purpose of this exercise has been to place space disposal in context with other suggested methods for nuclear waste disposal and from this to clarify the reasoning that might lead to the space option being chosen in the face of its clearly higher cost and operational hazards.

Notes to Chapter 2

1. A. Weinberg, "Social Institutions and Nuclear Energy" Science 177, 27 (1972).
2. H. Arendt. The Human Condition, University of Chicago Press, Chicago, 1958.
3. C. Smith, Risk Assessment for the Disposal of High Level Radioactive Wastes, Unpublished Ph.D. Dissertation, Dept. of Nuclear Engineering, U.C.L.A., 1975.
4. K. Arrow, "Social Responsibility and Economic Efficiency," Public Policy XXI, 303, 1973.
5. N. Georgescu-Roegen, "Energy and Economic Myths," Southern Economic Journal 41, 347, 1975.
6. M. P. Golding, "What Is Our Obligation to Future Generations?" Unpublished working paper, Hastings Center, Hastings-On-Hudson, N.Y. 1971.
7. D. Callahan, Ibid.
8. H. Jonas, "Technology and Responsibility: Reflections on the New Tasks of Ethics," Social Research 40, 31, 1973.
9. "Let justice be done though the world perish." A precept of classic Roman law, one of the foundations of the Western legal system.
10. Various estimates have been made in such documents as BNWL-1900 and WASH-1297. We draw upon F. Perret, Radioactive Waste Storage and Disposal: Methodologies for Impact Assessment, Ph.D. Dissertation, School of Business Administration, University of California, Berkeley, 1975, as being more timely.
11. R. Budnitz has suggested this analogy. If a peanut butter and jelly sandwich is dropped face down in the sand at the beach, the process is physically and technically reversible. All one has to do is use a magnifying glass and a tweezer to pick out the sand. However time consuming and impractical, this is clearly not impossible.

12. The Mycanaean tablets written in Linear B were deciphered only a few years ago. The 6000 years that have elapsed since they were sealed up for later discovery by the destruction of Mycenaea is only about 1/4 of the half-life of ^{239}Pu. Yet, not only was the language of the Mycanaeans lost, the tablets resisted all attempts at decipherment for many years after they were discovered. These tablets were found together with a number of storage jars and other artifacts. Supposing the message had read: "Warning, these jars are filled with an invisible and slow-acting poison." How could we have even known that the tablets were meant as a warning?

13. That is, to the level in currently mined sandstone ores. Reducing to the hazard level of pitchblende or other rich ores would not do. Many miners have died in mines containing uranium-bearing ores over the years. The classic case is Joachimstaal in Czechoslovakia, where records of deaths associated with radiation sickness go back hundreds of years. The fact that a few hazardous deposits have existed does not assign the right to create more.

14. Of course, we could decide that the danger to the future from the rediscovery of nuclear fission weapons presents a sufficient hazard that we should not leave fissionable materials about in recoverable form at all, under the assumption that this civilization will be lucky if it survives its discovery of the fission bomb and that the future may have worse luck (if possible). As an ethical problem, this is considerably more tangled than any other we have so far raised.

15. M. Landau, "Redundancy, Rationality, and the Problem of Duplication and Overlap," Public Administration Review, July-August 1969, p. 346.

16. The idea of multiplicity is difficult to apply to space dispoal operations. For earth orbit, one could compare bunching all the containers together with a number of mathematically identical but spatially separated orbits. For solar escape, the "sites" are all separated even if the trajectories are the same, since the configuration of the planets and other objects that might cause an orbit to close back on Earth will change with each shot. Therefore, we take multiplicity to be roughly equal to the number of missions for solar escape.

17. This chapter draws heavily upon the ideas developed in G. I. Rochlin, "Irreversibility and Multiplicity: Two Criteria for Disposal of Nuclear Waste," Working Paper No. 18 (Institute of Governmental Studies, University of California, Berkeley, California, 1976), to be published in Science, January 1977.

CHAPTER 3

TECHNICAL DETERMINANTS: NUCLEAR POWER GROWTH - 1975-2000

The size and scope of any NASA program to dispose of some portion of the wastes from the nuclear fuel cycle would depend on the growth and technical characteristics of the nuclear power industry over the next few decades. A precise determination of the quantities and character of the wastes that the space disposal option might be requested to handle would be difficult under the best of circumstances, given the uncertainties in even the most accurate of forecasting methods for the growth of nuclear power.

The large lead time required from the original commitment to purchase or construct a nuclear facility to its completion does provide some ability to forecast over five to ten years with a modicum of confidence. Longer term trends, however, are harder to establish. Present nuclear power plant designs are very capital intensive.[1] A continuation of the current combination of inflation and plant cost escalation[2] together with very tight capital markets might result in continued delays and cancellations in new plant construction. On the other hand, the development of increasing capital liquidity and standardization of plant design (which could counter the trend towards increasing costs) could accelerate nuclear power growth in the future. Other factors, such as intervenor suits against licensing, the price and availability of coal and oil, and the net economic growth in other sectors may also exert considerable influence. Table 3.1, adapted from an econometric study by Joskow and Baughman[3] well illustrates the sensitivity of nuclear power growth projections to such externally determined factors.

Even in the absence of such considerations, projections for the growth of the U.S. nuclear power industry vary considerably, as shown on Fig. 3.1. Curve A on this figure is the lowest growth projection (Case A) of WASH 1139(74),[4] the last of a series of projections made by the AEC before it was split into ERDA and the NRC by the implementation of the Energy Reorganization Act of 1974. This was a pessimistic projection as of 1973, based on the assumption that the construction and licensing delays then plaguing the industry would continue for some time. It did, however, also assume that there would be a considerable installed capacity of high-temperature gas-cooled reactors (HTGR) and liquid-metal cooled fast-breeder reactors (LMFBR) by the year 2000. With 1974 being a year of increased difficulties for the nuclear industry, many reactor orders being either delayed or cancelled, this old 'low' AEC case was substantially the same as the highest projections used in the first forecast made by ERDA after its formation. In ERDA-48,[5] the mandated first report

TABLE 3.1

SENSITIVITY OF PROJECTED GENERATION CAPACITY TO SOCIO-ECONOMIC FACTORS*

(GIGAWATTS ELECTRIC)

TOTAL CAP.	BASE CASE	CASE # 2	CASE # 3	CASE # 4a	CASE # 4b	CASE # 5	CASE # 6	CASE # 7
1980	696	686	679	684	684	695	661	696
1985	820	786	809	780	774	857	739	811
1995	1158	1207	1154	1063	1004	1194	1050	1214
NUCLEAR CAP.								
1980	80	80	87	80	80	80	80	80
1985	193	176	212	201	201	252	177	147
1995	497	297	621	513	525	480	375	203

Taken from Joskow and Baughman, Ref. 3.

BASE CASE: \$11/bbl. oil, coal at currently expected prices, no gas for electricity air pollution costs in center of current predictions.

CASE 2: <u>No O.P.E.C.</u> Like base case, but fuel prices escalated at 2%/yr from 1973 prices.

CASE 3: <u>High Air Pollution Restrictions</u>. Like base case, but with increased costs of 2.8 mills/kwh for coal and increase in coal and oil plant costs.

CASE 4a: <u>Peak Load Pricing</u>. Instituted in 1975 with load factor improved 10% by 1985.

CASE 4b: <u>Peak Load Pricing</u>. Instituted in 1975 with load factor improved 20% by 1985.

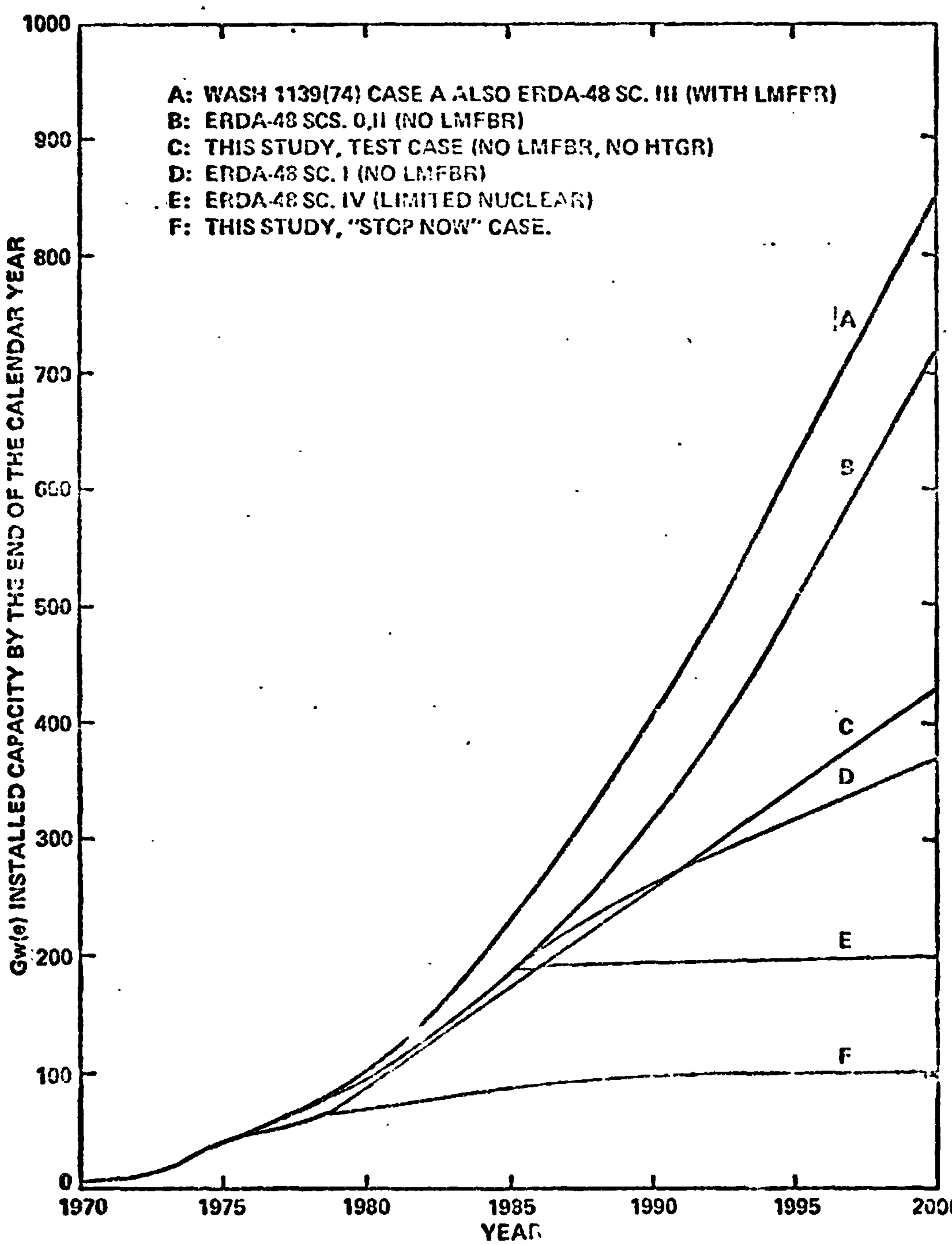
CASE 5: <u>Decreased Nuclear Lead Times</u>. Lead times red' :d from 10 years to 7.

CASE 6: <u>High Costs of Capital</u>. Utility capital charge rate increased from 15% to 18%.

CASE 7: <u>High Costs of Uranium Ore and Enrichment</u>. The cost of U_3O_8 is assumed to rise from present \$8-10 per pound to \$20-25 per pound by 1985, while enrichment increases to \$80/SWU. By 1995 costs will have risen to \$72/lb for U_3O_8 and \$138/SWU in current dollars (\$22/lb and \$43/SWU in 1974 dollars).

Figure 3.1

NUCLEAR POWER GROWTH PROJECTIONS TO THE YEAR 2000



of ERDA on the status of its programs, Scenario III--intensive electrification--closely approximated Case A of WASH-1139(74) except for a small reduction in the estimated LMFBR capacity.

We have chosen to omit the LMFBR as a source of radioactive waste in this study.[6] The net amount of installed LMFBR capacity by the year 2000 would not be large enough to affect waste management decisions made within the time frame we are considering. We have also chosen to omit both the HTGR and the proposed light-water breeder reactor (LWBR) from this study. The HTGR has suffered a number of setbacks to commercialization.[7] There is at present no vendor offering such a unit, and only a single large plant will be operating in the near future.[8] The LWBR is still in the conceptual design stage,[9] and not being too actively promoted at the moment. It will certainly contribute no significant capacity by the year 2000 unless there is a significant shift in ERDA and vendor priorities over the next five years.

The omission of these three classes of reactor--LMFBR, HTGR, and LWBR--from consideration considerably eases our evaluation of the technical determinants of the waste management problem. The LMFBR would produce a markedly different mix of isotopes in its waste stream, particularly so for high atomic number actinides.[10] The HTGR and LWBR run on an entirely different nuclear fuel cycle--the Thorium-Uranium cycle--than do standard LWRs (light-water reactors) and proposed LMFBRs, and would present a different, although related, set of problems for waste disposal.[11]

As a result of these considerations, we have chosen to restrict this study solely to the wastes produced by commercial l[illegible]-water reactors (LWR) similar to those now in operation. Even if some LMFBR or HTGR capacity exists, the LWRs will provide the bulk of the wastes to be disposed of during the 1975-2000 period analyzed in this study. Curve B, the most optimistic of the ERDA-48 projections in the absence of significant commercial LMFBR capacity by the year 2000, may then be taken as an upper limit projection for the purposes of this study. It corresponds to both Scenario 0--business as usual--and Scenario II--extensive use of synthetic fuels--of ERDA 48.

Curve D is the energy conservation scenario of ERDA-48, Scenario I for improved efficiencies in end use of energy.[12] This projection is fairly low for ERDA, but corresponds rather well to many projections made by more conservative outsiders such as the Ford Foundation Energy Policy Project. Although this case is driven by conservation alone, a combination of more modest conservation efforts and continuing economic difficulties for the nuclear power industry could well have a similar effect on reducing the use of nuclear fission power even if total electric power grows somewhat more rapidly than the scenario predicts.

ERDA-48 also contains an ultra-low projection, shown as Curve E. Scenario IV, represented by this curve, is meant to represent a sudden decision on the part of society to terminate all new construction of nuclear fission power plants after 1985. The sharp knee in this curve is derived from the assumption that all plants presently ordered or planned for completion before 198[illegible] are constructed as planned and on schedule. This seems unrealistic. As an alternative, we have constructed Case F as the lowest conceivable projection for nuclear power to the year 2000 under the assumption that no completed plant will be forced to shut down or reduce its operating capacity, but that a social or political decision to terminate all further development of nuclear fission is made in the next year or two. We assume that those plants for which a substantial amount of site work has already been done will eventually be completed and operated, albeit at a gradual pace that reflects delays for more comprehensive environmental and site surveys. The purpose of taking such a case is to examine whether the space disposal option could reasonably be expected to play a role in a socio-political decision to terminate all use of fission power as soon as possible and to remove all hazardous byproducts of the nuclear fuel cycle as completely as possible from the human environment during the operating life of the existing plants.

Case C, however, is the central projection to be used for the purpose of determining waste disposal parameters in this study. It must be emphasized that this is not a "projection" of nuclear power growth in the usual sense. It is a heuristic device to allow the calculation of types of quantities of wastes that space disposal might be called upon the deal with. As it corresponds fairly well to several other growth projections, such as Scenario I of ERDA-48, it is a not unreasonable projection; furthermore, it is also within the range of current econometric estimates that reflect the trend to increasing cost escalation and further delays in plant construction schedules. By taking a mid-range projection, we avoid the possibility of appearing to bias the case for or against the space disposal option by assuming unreasonably high or low values. Yet, the values we do chose are not so different from current high projections as to preclude the adaptation of the results of this study to them without doing violence to the assumptions we make.

Given that a projection in this range is desirable, Curve C has certain advantages for analysis. A linear growth model for installed LWR capacity from 1985 to 2000 is used, which simplifies estimations of wastes. From the point of view of impact analysis, this is also a conservative estimate, for not only the size of the industry but its rate of growth present social, economic, and political problems. By assuming a constant growth rate, we limit the effects of increasing scale of operation largely to those arising in the waste management itself. The precise end point of the model--430 Gw(e) in the year 2000--was also chosen to simplify estimates. This industry size is identical to that used for detailed analysis in WASH-1327, the draft Generic Environmental Statement on the Use of Mixed Oxide Fuel (commonly known as GESMO).[13] Many of the relevant calculations made in the draft GESMO can therefore be taken over directly for our purposes. The one major emendation is the stretching out of the time scale to correspond to our model calculation. The analysis year of 1990 predicates more rapid growth than we have assumed here. Our model assumes a constant growth rate of 17 Gw(e) installed capacity per year between 1985 and 2000. We also assume that the mix of LWRs will tend to 2/3 pressurized water reactors (PWR) to 1/3 boiling water reactors (BWR) by the year 2000.

The other factors regarding LWR operations are of some interest to us in estimating quantities and types of waste. The availability factor of a react[illegible] [illegible]sures the total fraction of time that a plant is capable

TABLE 3.2

CAPACITY FACTORS FOR LIGHT-WATER REACTORS

Pre-Operational Phase	40%	
First Two Years of Commercial Operation	65%	
Years 3 through 15:		
High Case	75%	(790 GW(e) by 1995)
Moderate/High	72%	(640 GW(e) by 1995)
Moderate/Low	70%	(545 GW(e) by 1995)
Low Case	70%	(445 GW(e) by 1995)
Years 15 through end of Commercial Life	decline at 2%/yr.	
Minimum at End of Life	40%	

Source: Energy Research and Development Administration, 1976.

of generating power. The capacity factor (C.F.), on the other hand, is obtained by dividing the total number of kw-hrs delivered during a given year by the maximum obtainable energy (the total electrical capacity at full power multiplied by 8760 hours/year). Table 3.2 lists the expected C.F. performance of a typical LWR as a function of age.[15] Unfortunately, the C.F. of nuclear plants has become the focus of some controversy over specifications, and the consequence has been some juggling both of numbers and of definitions.[16] We take the full power rating of the plant to be defined by the core size and power density and the fuel burn (to be specified below), and define the capacity factor accordingly.

Table 3.3 lists the installed LWR capacity at the end of each calendar year to the year 2000 for Case C of Fig. II.1, our primary test case. The capacity factors listed extrapolate from presently known figures for past years[17] to a projection slightly more optimistic than mid-range ERDA values. The LWR "burn" column lists the average electric power actually delivered during the listed year (that is, installed capacity x capacity factor). Although not commonly referred to, this number has profound implications for fuel cycle and waste management since, with appropriate operating conditions, the fuel burn and quantity of fuel removed each year should be determined by the delivered power rather than the installed capacity.

The Nuclear Fuel Cycle

As with other energy technologies, the generation of electricity by LWRs entails the production of effluents and wastes at many points in

TABLE 3.3

CASE "C" PROBABLE NUCLEAR GROWTH TO THE YEAR 2000 and WASTE PROJECTIONS

				C_1 *		C_2 **		
YEAR	LWR cap. GW(e)	C.F.	LWR burn GW(e)	Mg spent fuel annual	Mg spent fuel cum.	Mg spent fuel annual	Mg spent fuel cum.	annual reprocessing capacity (Mg)
1973	23.2							
1974	30.4 #	.52 #	15.8		926 #		926	
1975	40.2	.53	21.3	700 ##	1626 ##	700	1626	0
1976	46.9	.54	25.3	1000	2626	1000	2626	0
1977	54.6	.55	30.6	1325	3950	1325	3950	0
1978	61.7	.56	34.6	1550	5500	1550	5500	0
1979	72	.58	41.8	1800	7300	1800	7300	0
1980	88	.59	51.9	2000	9300	2000	9300	500
1981	107	.6	64.2	2400	11700	2400	11700	1000
1982	124	.6	74.4	2900	14600	2900	14600	1500
1983	141	.61	86	3500	18100	3300	17900	1500
1984	158	.62	98	4100	22200	3600	21500	1500
1985	175	.63	110	4650	26850	3900	25400	2000
1986	192	.64	123	5200	32050	4100	29500	2500
1987	209	.65	136	5800	37850	4300	33800	3000
1988	226	.66	149	6350	44200	4500	38300	3000
1989	243	.67	163	6900	51100	4700	43000	3000
1990	260	.68	177	7500	58600	5000	48000	3000
1991	277	.69	191	8000	66600	5400	53400	3500
1992	294	.7	206	8600	75200	5800	58200	4500
1993	311	.7	218	9150	84350	6200	65400	5500
1994	328	.7	230	9700	94050	6600	72000	6000
1995	345	.7	242	10300	104350	7000	79000	6000
1996	362	.7	253	10800	115130	7400	86400	6500
1997	379	.7	265	11400	126550	7800	94200	7500
1998	396	.7	277	11900	138450	8200	102400	8500
1999	413	.7	284	12500	150950	8600	111000	9000
2000	430	.7	301	13050	164000	9000	120000	9000

* Assumes annual refuel for design base of 33,000 MWd_{th}/Mg at 100% C.F.

** Assumes shift to full 33,000 MWd_{th}/Mg burn by the year 1990

\# Actual data compiled from ERDA and industry reports

\#\# Data obtained from ERDA-25

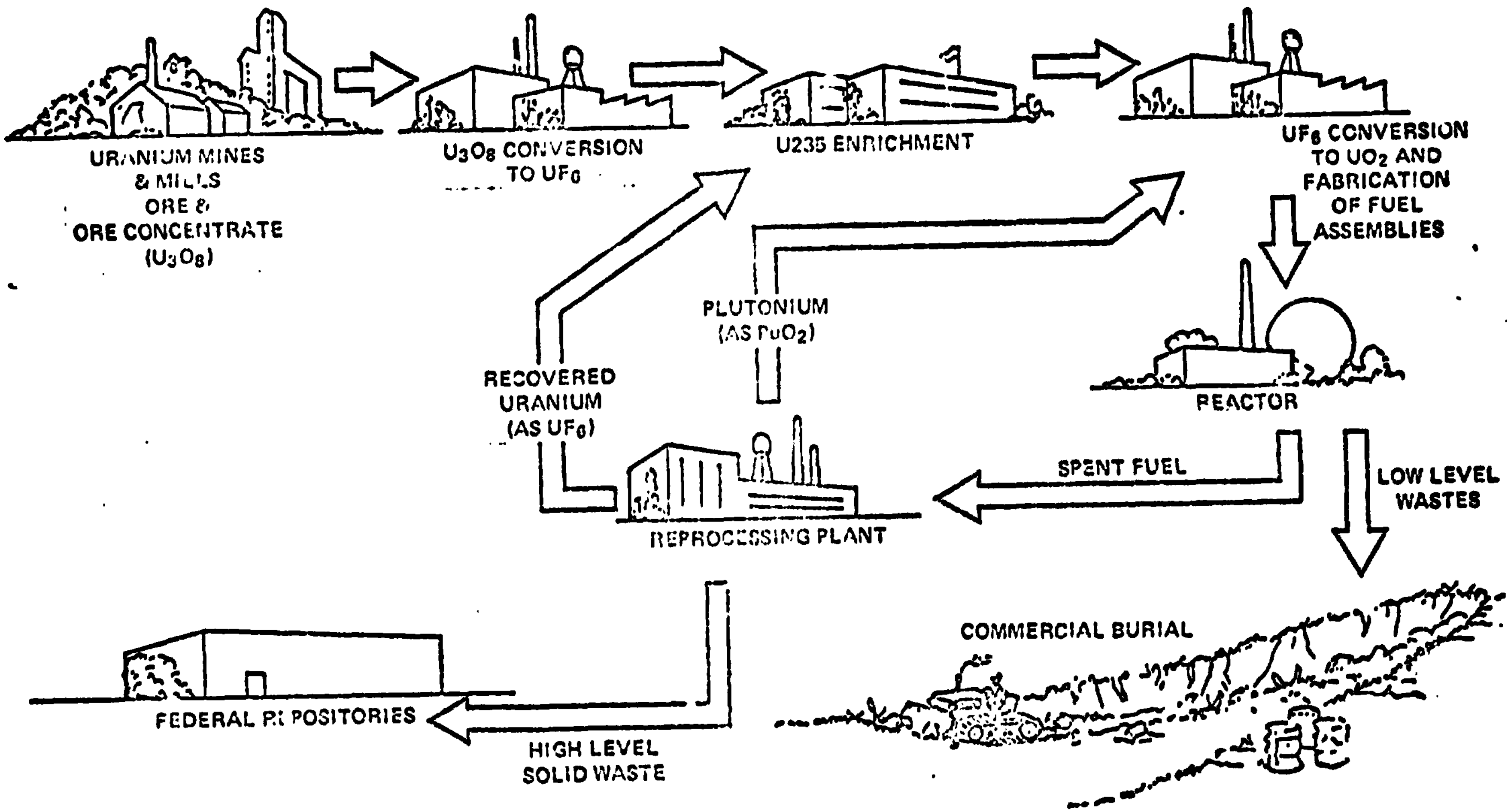


Figure 3.2

LIGHT WATER REACTOR FUEL CYCLE WITH PLUTONIUM RECYCLE the cycle from the extraction of ore to the ultimate disposal of high-level wastes. Most competing technologies, however, use a "throw-away" fuel cycle, in which the energy source is mined or extracted, consumed, and the residue disposed of. In contrast, the incomplete consumption of fissile ^{235}U and the production of fissile ^{239}Pu in the operation of LWRs has led to proposals to "close" the nuclear fuel cycle by reprocessing the spent fuel to extract valuable U and Pu and recycling these back into the reactors. Such a complete fuel cycle is illustrated schematically in Fig. 3.2. Table 3.4 lists the definitions and sources of various types of wastes from the operation of this conceptual fuel cycle.

For simplicity, all fuel and waste quantities in the cycle are normalized by referring them to a hypothetical "model" PWR having a thermal efficiency of 32.5%, a specific core power density of 30 MW(th)/Mg (30 Megawatts thermal/metric tonne of fuel), and an electrical power output of 1 GW(e). Thus a total electrical capacity of, for instance, 200 GW(e) can be modelled by considering 200 such "model" reactors. Fig. II.3 is a flow chart for such a reactor.[18] The quantities listed on this figure assume a capacity factor of 100% (that is, operation at full power for 8760 hours during the year). The spent fuel figures assume the annual turnover of one-third of the PWR core. For a BWR, only one-fourth of the core is replaced annually. However, as the core itself is roughly 4/3 the size of a PWR core, spent fuel composition and quantities will be roughly the same, and no further distinction between the two types of LWR need be drawn.

In actual practice, reactors cannot be operated at capacity factors of 100%. The limiting availability factor is estimated to be 80 to 85%,

TABLE 3.4

WHAT ARE THE WASTES?

FISSION PRODUCTS:

From fission of uranium or plutonium. About 10kg per MW(e)-yr. Short to intermediate half-lives. Beta and gamma emitters.

TRANSURANICS:

From neutron capture by uranium or other transuranics. Quantity produced depends on reactor type and design. Long half-lives. Alpha emitters.

ACTIVATION PRODUCTS:

From neutron capture by and transmutation of non-radioactive materials.

EFFLUENTS:

Liquids or air containing radioactive materials or gases in small quantities.

CATEGORIES OF WASTES TO BE MANAGED

FROM REACTORS:

Fission products and transuranics from leaking fuel, activation products and materials contaminated with these. Low to intermediate concentration. Fuel containing residual uranium, plutonium, transuranics, fission products.

FROM FUEL PROCESSING:

High level wastes from solvent extraction; concentrated fission products with residual uranium and plutonium and the remainder of the transuranics.
Intermediate level wastes; less concentrated fission product contaminated chemical wastes and products from effluent cleanup.
Cladding hulls and activated fuel components.
Evolved gaseous fission products as effluents.
No liquid effluents will be allowed.

FROM FUEL REFABRICATION:

Transuranic contaminated solids.
Liquid effluent treatment sludges.

FROM ALL:

Low level wastes from contaminated gloves, wipers, boots, etc.

due to routine maintenance and refueling schedules. As we wish to determine the industry-wide average capacity factors, we should include an effective reduction owing to the operation of LWRs at less than full power during the initial start-up and towards the end of plant life, as in Table 3.2. The capacity factors shown in Table 3.1 represent a fairly optimistic judgment of the annual average capacity factor based on previous experience and the mix of new and old plants. These factors are somewhat lower than those in some industry documents, and slightly higher than in some ERDA estimates, but our results can easily be scaled by an appropriate multiplicative factor since they are within a few percent of other predictions.

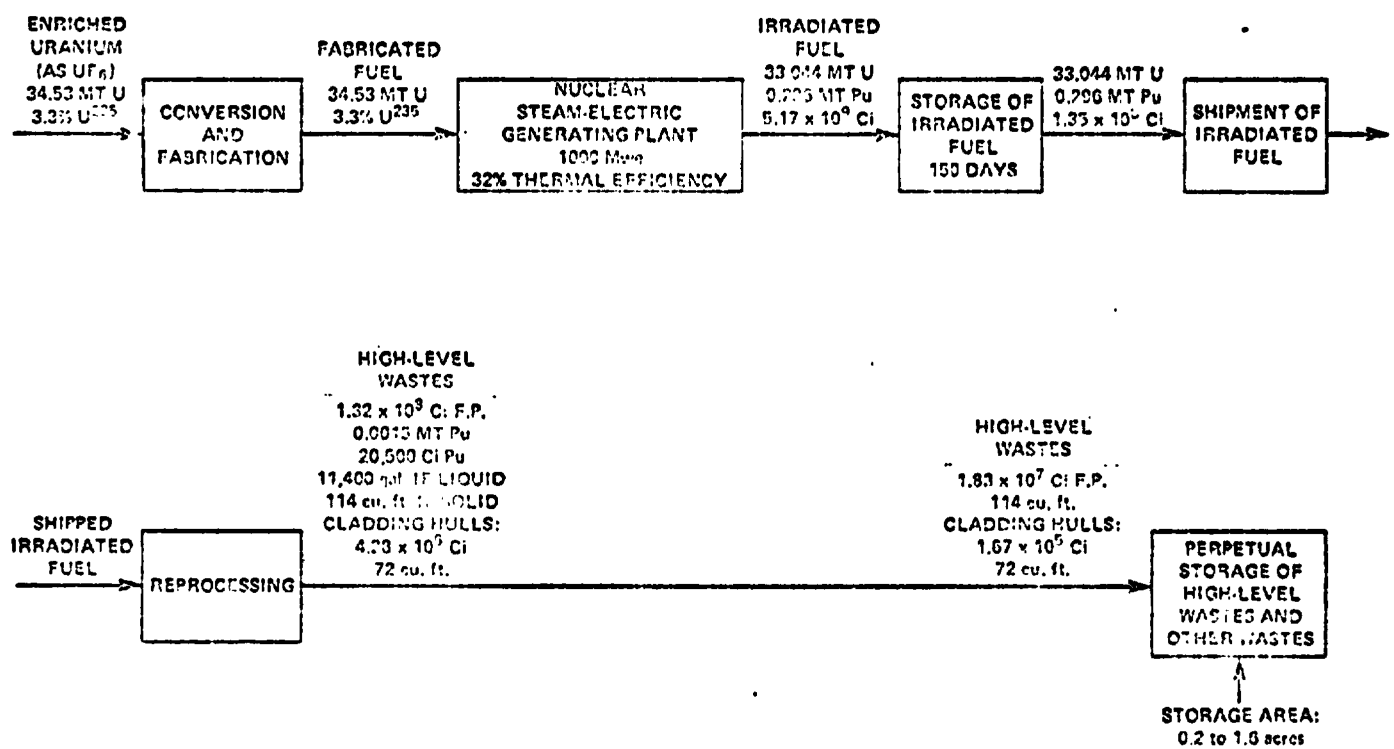
More important for this study is determining the best way to convert the data given in Fig. 3.3 on the basis of 100% capacity factor into actual quantities of spent fuel and waste, as this depends critically on decisions that are made regarding refueling operations and plant management. The common consensus among ERDA and industry documents is that present and future LWR fuel is adequate for a fuel burn of 33,000 MW(th)/Mg, corresponding to a full operating time of 1100 days at a specific power of 30MW(th)/Mg of fuel. The specified core turnover of 1/3 (for a PWR) or 1/4 (for a BWR) of the full core every year then results in the annual withdrawal of 33 Mg of spent fuel per year, irradiated to the full burn of 33,000 MWd(th)/Mg.

Given the lower capacity factors in actual practice, two fuel management decisions could be made. Current practice is to refuel the reactor and remove the spent fuel during annual inspection shutdowns. If this

Figure 3.3

FLOWSHEET FOR 1 Gw(e) URANIUM-FUELED LWR

ANNUAL QUANTITIES AT 100% CAPACITY



Source: Pigford, Ref. 18

WOOD

practice is continued, 33 Mg of spent fuel will be removed each year for every GW(e) of installed capacity. This is the projection used to generate case C_1 of Table 3.3. Our projections for this case duplicate almost exactly the waste projection for the period 1975-1982 that were made in ERDA-25.[19] As ERDA-25 is compiled from actual industry estimates for real plants, the accuracy of our model is confirmed by this agreement. For this case, the reduced capacity factor results in a reduction in irradiation of the spent fuel rather than mass. For instance, at a capacity factor of 70%, the average spent fuel irradiation would be (0.7 x 33,000) or 23,100 MWd(th)/Mg.[2]

At present enrichment capacity is becoming both scarce and increasingly expensive.[21] There is also considerable pressure to use our limited resources of inexpensive and readily accessible U ores as efficiently as possible. These two factors may result in the alteration of the present policy of annual refueling, and a transition to a cycle in which the reactor is only refueled after each cumulated reactor-year of full-power operation. Each fuel element would then reside in the reactor for 1100 days at full power before removal, and all spent fuel would be irradiated to the full limit of 33,000 MWd(th)/Mg. In this case, the irradiation of spent fuel would remain constant, but the mass discharged annually would depend on the capacity factor for that year. A convenient shorthand method for calculating the spent fuel mass in this model is to note that 33 Mg of spent fuel are discharged for each GW(e)-year of delivered electrical energy (corresponding to the "burn" column of Table 3.3).[22] Case C_2 has been constructed to reflect the possibility that such a decision would be made in the near future. The assumption made is that the transition from annual refueling to demand refueling begins in the year 1982 and is essentially completed by 1990.

It should also be noted that the quantities of spent fuel listed in Table 3.3 are entered as of the year they would be shipped to the reprocessing plant. We have used the usual algorithm to take into account on-site storage for initial decay of short-lived isotopes, shipment times and schedules etc. and the waste quantities listed reflect the installed capacities as of two years earlier.[23]

At the present time, there is no reprocessing capacity available at all in the United States, and current spent fuel is being stored at reactor sites pending a decision as to further storage or initiation of reprocessing operations. Thus, although the nuclear fuel cycle is not a "throw-away" operation, it might be well characterized at present as a "stow-away" cycle. Current opinion within and without ERDA, NRC, and the industry is that the potential value of the spent fuel as a resource for U, Pu, and other potentially valuable isotopes is such that it will continue to be stored for future use even if the advent of reprocessing recedes into the far future.

For the time being, then, no wastes from the commercial nuclear fuel cycle are being produced in the concentrated, highly toxic forms that would lead to consideration of space disposal.[24] The only present byproducts of nuclear power operations are effluents and tailings, low-level and transuranic-contaminated wastes, and spent fuel elements. Of these, only the spent fuel begins to approach the conditions of high specific activity and relative concentration that might lead to consideration of space disposal. There is, of course, a possibility that, should reprocessing be decided against entirely or should alternative energy sources appear on the horizon, a decision might be made to treat the spent fuel as waste and dispose of it permanently. As can be seen from Table 3.3, this would involve the disposition of between 2000 and 10,000 Mg of spent fuel per year, together with associated shielding. Although this cannot be said to be an impossible task for space disposal, it most certainly exceeds present NASA plans and capabilities.

Towards the very low end of the range of nuclear power growth projections, however, there is a marginal possibility that space disposal might be used to eliminate the last vestiges of a nuclear fission power economy that is being phased out. In our Case F, for instance, the decision to terminate all use of fission power might be accompanied by a determination to dispose of all spent fuel as well. The requirements for a waste disposal operation would then remain at a relatively constant figures of about 2000 Mg per year for many decades. This case will be examined briefly in this report to determine whether such operations could be implemented even if they were desired. Nevertheless, as the probability that this will occur is quite low, we may safely assume that there will be no role at all for space disposal operations in the absence of operating facilities for the reprocessing of spent fuel.

Reprocessing

Owing primarily to the buildup of fission products in the fuel elements, they are removed from the reactor before all the fissile material is consumed. As can be seen from the data of Fig. 3.3, the considerable expense and effort that goes into producing fuel for a U-fueled LWR by isotopic enrichment of natural uranium from 0.7% ^{235}U to 3.3% ^{235}U produces about 1100 kg of fissile material in a total annual fuel charge of 34,000 kg. Even at the full fuel burn of 33,000 MWd(th)/Mg the U in the spent fuel is somewhat more enriched than natural uranium--about 0.83%--and has some value as a feed material for enrichment if it can be separated from the fission products and the other actinides. Furthermore, neutron absorbtion by ^{238}U produces ^{239}Pu, which is also a fissile material. When all the neutron absorption mechanisms and actinide chains are counted, there are about 210 kg of fissile Pu contained in the annual spent fuel discharge of 33,000 kg roughly the same mass as that of the remaining fissile ^{235}U. Thus, for an annual charge of about 1100 kg of fissile material, the reactor spent fuel stream contains almost 500 kg of fissile material which could be recovered and recycled back for use in reactors.[25] This is an appreciable fraction of the initial charge.

If the spent fuel is reprocessed to separate the U from the other material present, the resulting U stream could easily be fed back into the enrichment plant, decreasing the requirement for mining, milling, and concentration. The isotopic composition of the U in this case is such that there would be no radiological problems if the U stream were kept quite pure. Assuming that only the U is recycled back for re-use, this would mean a reduction of about 10% in requirements for U ores.[26] Reduction in enrichment requirements is quite sensitive to the actual U assay, but would probably be only one or two percent.[27]

High-level nuclear wastes consist of the balance of the materials in the fuel elements once the U and Pu have been removed. In the reprocessing operation, the long thin fuel pins are sheared into short sections and the contents dissolved out of the insoluble Zircalloy cladding. The irradiated Zircalloy, together with traces of undissolved fuel, is treated separately as intermediate level waste. As about 96% of the mass of the dissolved fuel is stable ^{238}U, the chemical extraction of U from the mixture removes the primary non-toxic dilutant, leaving a mixture consisting of a small fraction of unextracted U, and Pu, the balance of the other actinides, and the highly active fission products. Almost none of the radioactivity goes off with the U, and little with the Pu. The result of this process from the point of view of waste management is a roughly 20-fold concentration of the hazardous components of the spent fuel into liquid high-level wastes.[28]

Carrying out such a process without also extracting and separating out the Pu is held to be undesirable for several reasons. Pu separation has been practiced for decades as part of the nuclear weapons program and is a well understood process. If the Pu were not removed, its concentration in the waste stream would be sufficiently high to raise the possibility of a criticality incident.[29] The whole waste mass would have to be handled most carefully. It would also have to be safeguarded against possible diversion or theft. On the other hand, extracted Pu could be recycled back into reactors without going through expensive enrichment stages, or could be used to fuel breeder reactors. In either case, it has a high value. For these reasons, all reprocessing plans to date assume

C-2

that the Pu will also be extracted from the spent fuel during reprocessing, collected as relatively pure plutonium nitrate, and stored pending a decision on its further use.

With our previous assumption that the total mass of spent fuel will be too large for the space disposal method to be of interest, reprocessing is a necessary precondition. This situation surrounding the future of the fuel reprocessing industry is, however, sufficiently uncertain so as to preclude any appeal to authoritative outside sources for timetables and capacity. Therefore, a heuristic, but not unreasonable, estimate of the growth of the reprocessing industry over the years 1975-2000 has been constructed for the purpose of generating a set of numbers that can be used for further analysis in this study. Again, we emphasize that these are not predictions, in the ordinary sense, but rather a set of judgments that allow modelling to proceed on the basis of "what if...".

There are a few facts about the potential fuel reprocessing industry that are known well enough to allow the generation of short term predictions based on firm planning. Table 3.5 is a list of extant and planned fuel reprocessing facilities in the world. The only reprocessing plant presently committed in the United States is AGNS in Barnwell, South Carolina. The reprocessing portion of the plant is completed and undergoing tests, although waste handling and other support facilities needed for licensed operation are not yet in place. Start-up time for commercial operation at AGNS depends on the status of ERDA and NRC decisions, regulations, and hearings, and are the subject of some debate. We have taken a moderately optimistic tack and assume that AGNS will start commercial

TABLE 3.5

WORLDWIDE SUMMARY OF CURRENT AND PLANNED REPROCESSING PLANTS

LOCATION	OPERATOR	CAPACITY [Mg/yr]	OPERATING DATE	CURRENT STATUS
U.S.A.				
West Valley, N.Y.	NFS	300	1966-72	shut down for expansion
"	"	750	1980s	needs new construction permit
Morris, Ill.	GE	300	---	inoperable in present form
Barnwell, S.C.	AGNS	1500	1980	awaiting GESMO decision
Loudon, Tenn?	Exxon	2000?	mid-80s	uncertain at present
U.K.				
Windscale	BNFL	1500-2500	1964*	U metal only, near full capacity
" oxide plant	"	300	1972	shut down after incident
" oxide plant	"	400	1978	refurbished oxide plant
" new oxide plant	"	1000	1984	commercial, for domestic use
" new oxide plant	"	1000	1987	pending, for overseas contracts
France				
La Hague	CEA	300	1966*	U metal only, to be remodeled
"	"	150-800	1976	oxide, to be phased in
"	"	1000	1985	new oxide plant, planning phase
Marcoule	CEA	900-1200	1958*	old military U metal plant
Germany				
Karlsruhe WAK	KEWA	40	1970	pilot oxide plant
-----?	PWK/KEWA	1500	1984	commercial oxide, design stage
Japan				
Tokai Mura	PNC	200	1976	non-active: demonstration plant
---?	PNC	1000	late 80s	commercial, no site found yet
Belgium				
Mol	Eurochemic	60	1966	shut down; future in doubt
Italy				
Saluggia (Eurox 1)	CNEN	10	1969	pilot; shut down for modification
India				
Trombay	IAEC	60	1965	pilot; natural U oxide

*These plants do not process commercial oxide fuels from light-water reactors.

operation in 1980, approaching its full capacity of 1500 Mg per year by increasing annual capacity in 500 Mg steps.

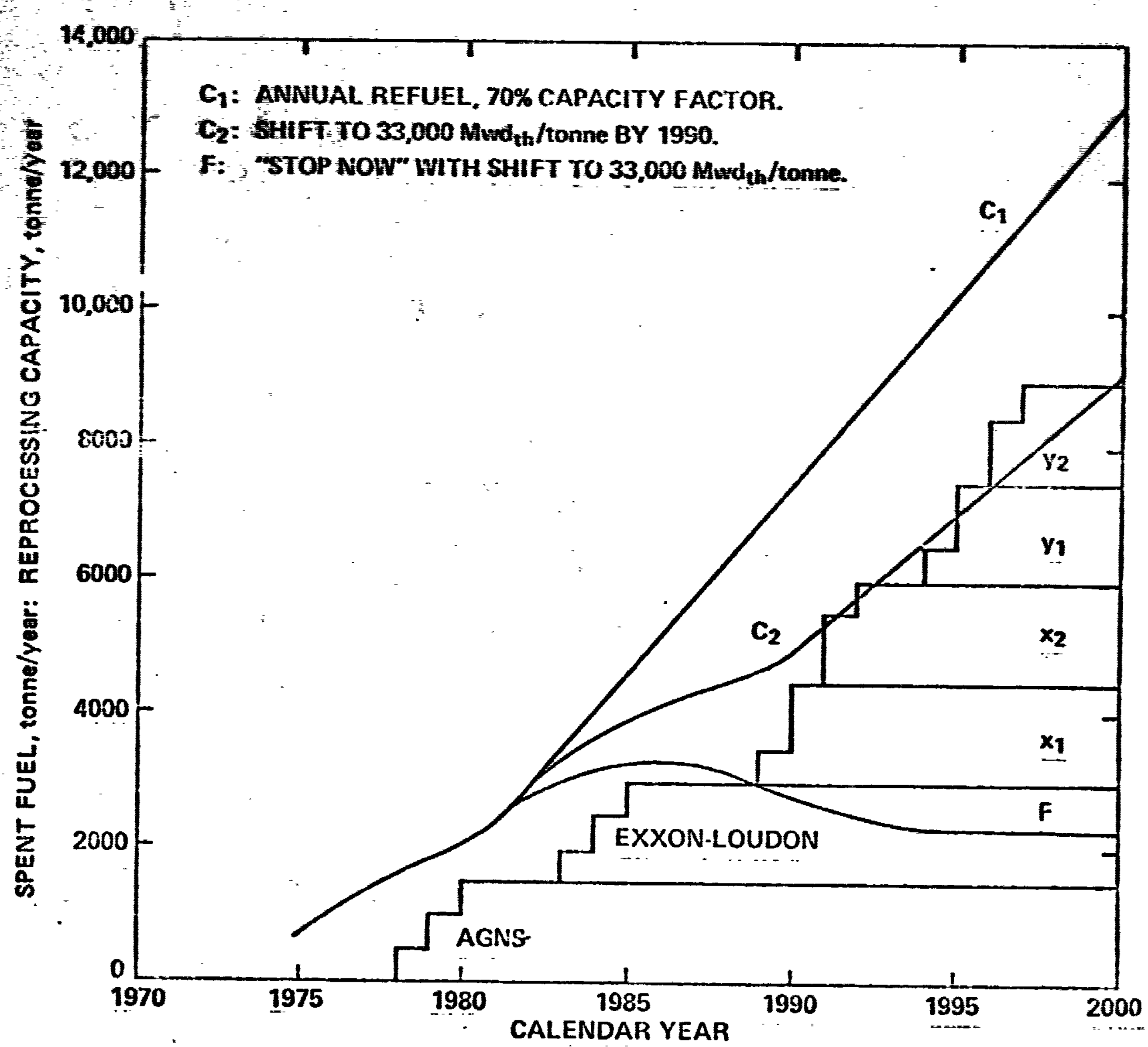
The only other firmly planned reprocessing facility is the proposed Exxon operation at Loudon, Tennessee. As no construction has yet been committed on this plant pending Exxon's determination of profitability and licensability, estimates of start-up time are difficult to make. We again take a reasonbly optimistic stance, and assume that present ERDA estimates of a 1985 start-up date are correct. As with AGNS, it is assumed that this plant will have a capacity of 1500 Mg per year, and that it will phase in by annual 500 Mg steps.[30]

The planning of new capacity is expected to be delayed until AGNS is licensed and operating experience is acquired. Taking our estimates for the date of AGNS operations and allowing for appropriate lead and construction times, we estimate that the earliest date for additional reprocessing capacity to come on line would be 1990. By this time, pressure on spent fuel storage would be considerable, and the rapid construction of new facilities would undoubtedly have high priority.[31] We estimate that the next installation would be a plant of 3000 Mg/yr capacity starting up in 1990, followed by another 3000 Mg/yr unit in 1995. As with reactors, it is most convenient to treat this capacity in terms of a "model" plant. Here we have taken a 1500 Mg/yr unit similar to AGNS as our model.

This amount of reprocessing capacity comes very close to closing the fuel cycle of Case C_2 by the year 2000. As shown in Fig. 3.4, additional capacity would be needed to handle the additional reactors beyond 2000.

Figure 3.4

SPENT FUEL AND REPROCESSING CAPACITY TO THE YEAR 2000: LWR-U ECONOMY



As the construction of any new capacity in the last few years of the selected 1975-2000 period has little, if any, effect on our results, and as we expect that the situation regarding the nuclear fuel cycle will be radically altered towards the end of the century by the advent of fusion power, breeder reactors, or other sources of energy, we terminate our heuristic model with the 1995 installation.

Even though there is a marked gap between the estimated reprocessing capacity and the amount of spent fuel generated by Case C_1 (which represents current practice), a comparison of our figures with statements from industry and government sources indicates that our estimates of reprocessing capacity are not likely to be exceeded in the absence of a crash government program to reduce spent fuel backlogs.[32] AGNS alone would provide sufficient Pu to start up even a quite rapid LMFBR program, so the level of commitment to the LMFBR over the stated time period is of little import.

As with the projections made for total installed nuclear capacity, the estimates made here for reprocessing capacity have the additional convenience of corresponding, in the year 2000, to the assumptions used to analyze the test year of 1990 in the draft GESMO. Once again, this enables us to take over their 1990 results directly for our year 2000 estimates.

It is important to note that the high-level wastes (HLW) are produced at the reprocessing plants, not the reactors. Therefore, it is the assumption as to net reprocessing capacity that governs the waste projections to be used in this study. Under the further assumption that no attempt will be made to dispose of undifferentiated spent fuel or other wastes from the nuclear fuel cycle via space disposal, the distinction between Cases C_1 and C_2 above is of little relevance to the waste mass to be handled. The different fuel burns assumed in these two cases will, however, make a difference in packaging the wastes for disposal, which will affect the number of shots to be made. This will be discussed in detail further on in this report.

Other Wastes

The types and quantities of wastes to be generated by an entire, closed nuclear fuel cycle have been listed in Table 3.4. It is unlikely that the combination of relatively high volume and low activity for wastes other than high-level from the reprocessing plants will be suitable for space disposal. The possible exception to this rule might be the disposal of radioactive noble gases, such as ^{85}Kr or ^{129}I.[33] The transport, packaging, and safety requirements for these present a quite different set of problems than for conventional HLW and, in the absence of present indications that space disposal would be used for the disposal of noble gases, they are not considered further in this report.

Characterization of High-Level Wastes

In order to examine the heat production and radioactivity of the HLW, both of which are critical for consideration of packaging for space disposal, some assumptions will have to be made about their isotopic composition. This will also affect their relative hazard to life and therefore the effects of accidents on land, in water, or in the atmosphere.

The masses to be dealt with, however, depend only on the installed reprocessing capacity and can be calculated using our previous estimates.

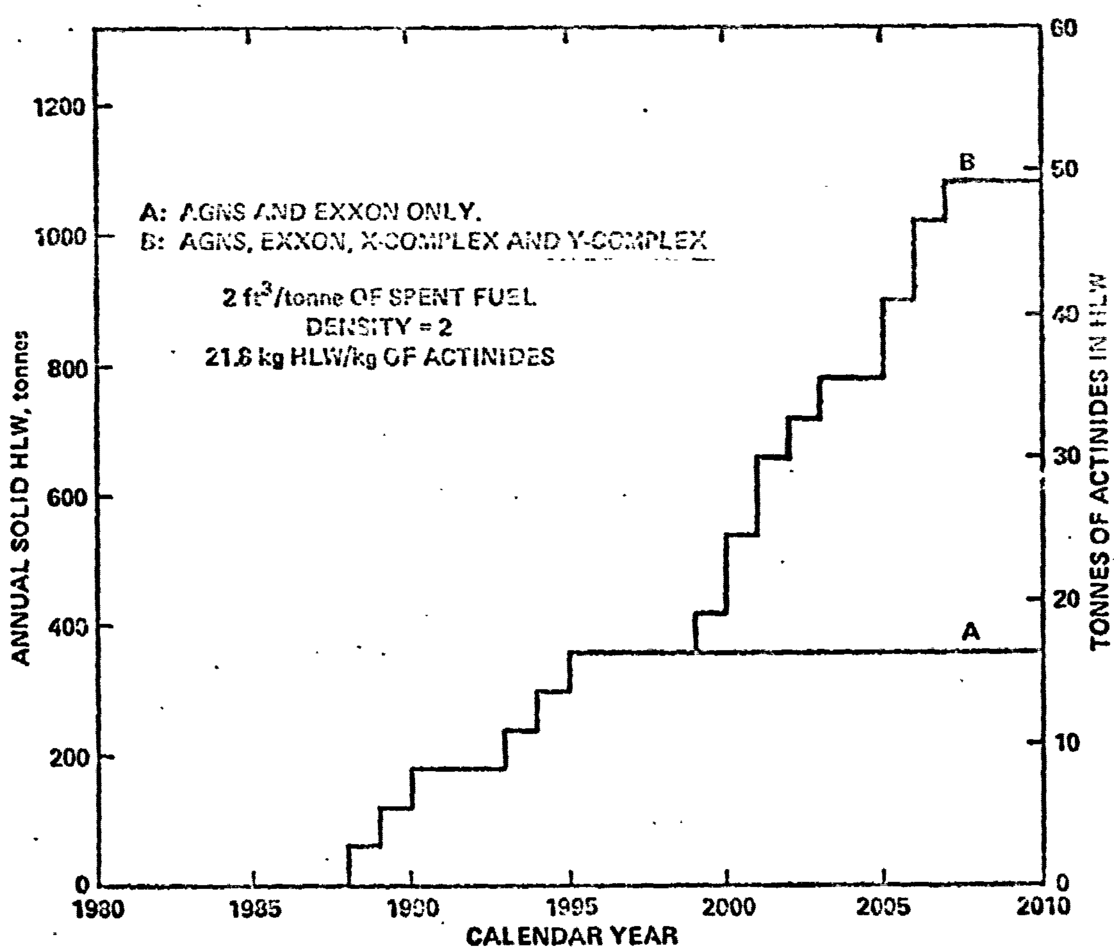
According to federal regulations, the HLW from reprocessing can be held as liquids for no more than five years.[34] They must be solidified within this time and may then be held for an additional period (but not longer than ten years from their date of production) before being shipped for storage and disposal. For the purposes of this report, we assume that the wastes are held at the reprocessing plant for the full ten years before being shipped. This is a particularly reasonable assumption for space disposal, since the wastes continue to decay and get easier to handle as each year goes by.

Several processes have been suggested for solidification of HLW.[35] Again, we must make a set of assumptions for the purposes of this study. We will assume that the solidified HLW will have a density of 2, independent of their form, and that 0.057 m^3 (2 ft^3) if solid waste are produced per Mg of spent fuel. This corresponds to the GESMO assumption that 3.14 Mg of spent fuel reprocessed will generate the amount of solidified HLW to fill a standard 0.18 m^3 (6.28 ft^3) shipping canister. Figure 3.5 shows the quantity of HLW solids that would be produced by the reprocessing capacity shown in Fig. 3.4. The solid HLW listed for the years of shipment, 1990-2010, correspond to spent fuel reprocessed in the years 1980-2000.

The total mass of HLW as stated above is relatively insensitive to reactor operating conditions, but the specific production of some of the more hazardous and difficult to deal with transuranics is not. Making the usual assumption of 99.5% extraction of U and Pu from the spent fuel, there will be about 5 kg of U and less than 100 g of Pu in the HLW per

Figure 3.5

ANNUAL PRODUCTION OF HIGH-LEVEL WASTE SOLIDS; LWR-U: AGED 10 YEARS AFTER REPROCESSING



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tonne of spent fuel, compared to about 29 kg of fission products (if the fuel is burned for the full 33,000 MWd(th)/Mg). When the masses of the various reprocessing chemicals and materials used in solidification are added,[36] the HLW from 1 Mg of spent fuel amount to about 115 kg. For Case C_1 in which the fuel is burned for an average of only 23,000 MWd(th)/Mg, the solidified HLW mass would be expected to be somewhat less per Mg of fuel. How much less is not clear. If all masses are proportional to fission products, and fission products are proportional to burn, then we would expect a reduction of about 30% in the HLW production from the stated reprocessing capacity. The reduction will probably be less than this, but certainly greater than just the few kg reduction in fission product mass. As the only good calculations available to us are for burns of 33,000 MWd(th)/Mg, we will continue to use this figure as a benchmark, thus implicitly accepting the validity of case C_2. Should case C_1 prove closer to the mark, we suggest that this would reduce the total HLW mass by 20% ± 10%.

Tables 3.6(a) and 3.6(b) list the composition, activity, and thermal power of spent fuel from a LWR-U cycle per tonne of spent fuel for HLW aged 150 days before reprocessing and for reprocessed fuel stored for 10 years afterwards. The fission products consist primarily of ^{90}Sr and its daughter ^{90}Y, and ^{137}Cs and its daughter ^{137}Ba. These data, based on the ORIGEN code developed at the Oak Ridge National Laboratory,[37] are for model Diablo Canyon LWR-U fuel burned at the specified 20MW(th)/Mg for 1100 days. The data for this fuel are available for all shorter burn times

TABLE 3.6 (a)

MASS, ACTIVITY, AND THERMAL POWER OF IMPORTANT ISOTOPES CALCULATED TO BE PRESENT IN MODEL LIGHT-WATER REACTOR REFERENCE URANIUM FUEL PER METRIC TON (Mg.) OF FUEL CHARGED TO THE REACTOR: 150-DAY AGED.*

NUCLIDE	MASS grams	ACTIVITY Curies	THERMAL POWER watts
Curium	35.3	17,400.	638.
Americium	153.	226.	7.3
Plutonium	9,080.	118,000.	123.
Neptunium	762.	17.9	0.005
Uranium	955,000.	0.9	0.002
Total Actinide	965,000.	136,000.	769.
Europium	182.	13,400.	71.7
Samarium	808.	1,150.	2.0
Prometheum	107.	99,800.	56.5
Neodymium	3,910.	51.	0.14
Praseodymium	1,200.	771,000.	5,730.
Cerium	2,880.	827,000.	787.
Lanthanum	1,270.	495.	8.2
Barium	1,390.	100,000.	392.
Cesium	2,720.	320,000.	2,410.
Yttrium	468.	235,000.	1,040.
Strontium	896.	173,000.	445.
Krypton	373.	11,200.	18.
Other Products	18,800.	1,840,000.	8,340.
Total Fission Products	35,000.	4,390,000.	19,300.
TOTAL	1,000,000.	4,526,000.	20,070.

*Source: ORIGEN Code, Ref. 37.

TABLE 3.6 (b)

MASS, ACTIVITY, AND THERMAL POWER OF IMPORTANT ISOTOPES CALCULATED TO BE PRESENT IN MODEL LIGHT-WATER REACTOR REFERENCE FUEL PER METRIC TON (Mg) OF FUEL CHARGED TO THE REACTOR. WASTES PROCESSED AT 150 DAYS WITH 99.5% EXTRACTION OF PU AND U, AND STORED FOR TEN YEARS.*

NUCLIDE	MASS gm	ACTIVITY Ci.	THERMAL POWER watts
Curium	21.3	1,730.	60.5
Americium	145.	200.	6.4
Plutonium	58.	452.	3.6
Neptunium	762.	17.9	0.005
Uranium	4,780.	0.006	0.00016
Total Actinide	5,760.	2,405.	70.6
Europium	164.	4,670.	42.4
Samarium	904.	1,070	1.9
Prometheum	8.5	7,870	4.1
Praseodymium	1,200.	150.	1.1
Cerium	2,640.	150.	0.1
Barium	1,790.	79,800.	313.
Cesium	2,320.	93,700.	226.
Rhenium	392.	550.	5.3
Ruthenium	2,140.	550.	0.03
Yttrium	465.	60,500.	346.
Strontium	778.	60,500.	78.8
Krypton	360.	6,050.	9.7
Other Products	21,840.	1,440.	1.6
Total Fission Product	35,000.	317,000.	1,030.
TOTAL	40,760.	319,400	1,100.

Source: ORIGEN, Ref. 37.

and may also be used to generate data for cases such as C_1 where the assumed burn time is shorter.

Table 3.7 lists some important hazardous isotopes present in the solidified HLW, as well as their half-lives, decay modes, and toxicity. The toxicity is measured by two related hazard indices: the maximum permissible concentration (MPC) of the given isotope in air or in water; and a reciprocal index, the volume of air or water needed to dilute the amount of this isotope generated in one year of operation of a "model" 1 (GW(e) LWR reactor at 100% C.F. to the allowable MPC level.[38] Figure 3.6 is a comprehensive plot of the radioactivity in the HLW solids from this model reactor as a function of time after discharge. It should be noted that for time exceeding a few hundreds of years, the activity in the wastes is dominated by the remaining Am and Pu and by the fission products ^{99}Tc and ^{129}I.

The HLW constituents divide fairly neatly according to the type and duration of the hazard presented. With the exception of ^{99}Tc, with a half-life of 2.1 x 10^5 years, and ^{129}I which presents rather special problems, fission products have half-lives that are short enough so that isolation from the biosphere for one or two thousand years should reduce the activity to near-background levels. Furthermore, the decay modes are primarily beta and gamma emission, whereas the longer-lived actinides are strong alpha-emitters. With the notable exception of ^{241}Pu, which is a strong beta emitter with a 13.2 year half-life, most of the actinides are radiologically hazardous as emitters of 5 to 6 MeV alpha-particles. Per Ci of activity, carcinogenic effects in situ should be roughly the same for alpha-emitting isotopes of all the actinides. The greater attention

TABLE 3.7

PROPERTIES OF SOME SIGNIFICANT RADIONUCLIDES IN HIGH-LEVEL WASTES FROM REPROCESSED LWR-U FUEL*

ISOTOPE	HALF-LIFE [yrs]	MPC(AIR)** [Ci/m^3]	MPC(WATER)** [Ci/m^3]	UNIT INHALATION HAZARD#		UNIT INGESTION HAZARD+	
				10 yrs	300 yrs	10 yrs	300 yrs
^{244}Cm	17.6	$3x10^{-13}$	$7x10^{-6}$	$4.3x10^{15}$	$8.2x10^{10}$	$1.8x10^{8}$	$3.5x10^{3}$
^{243}Am	7,950	$2x10^{-13}$	$4x10^{-6}$	$9.1x10^{13}$	$8.8x10^{13}$	$4.5x10^{6}$	$4.4x10^{6}$
^{241}Am	458	$2x10^{-13}$	$4x10^{-6}$	$8.1x10^{14}$	$5.5x10^{14}$	$4.1x10^{7}$	$2.7x10^{7}$
^{240}Pu	6,580	$6x10^{-14}$	$5x10^{-6}$	$7.6x10^{13}$	$1.4x10^{14}$	$9.1x10^{5}$	$1.7x10^{6}$
^{239}Pu	$2.4x10^{4}$	$6x10^{-14}$	$5x10^{-6}$	$2.7x10^{13}$	$2.9x10^{13}$	$3.2x10^{5}$	$3.5x10^{5}$
^{238}Pu	86.4	$7x10^{-14}$	$5x10^{-6}$	$1.2x10^{15}$	$1.8x10^{14}$	$1.8x10^{7}$	$2.5x10^{6}$
TOTAL ACTINIDES PLUS DAUGHTERS				$6.9x10^{15}$	$1.0x10^{15}$	$2.6x10^{8}$	$3.7x10^{7}$
^{154}Eu	16	$1x10^{-10}$	$2x10^{-5}$	$4.5x10^{13}$	$1.6x10^{8}$	$2.2x10^{8}$	$7.8x10^{2}$
^{151}Sm	90	$2x10^{-9}$	$4x10^{-4}$	$5.4x10^{11}$	$5.7x10^{10}$	$2.7x10^{6}$	$2.9x10^{5}$
^{137}Cs	30	$5x10^{-10}$	$2x10^{-5}$	$1.7x10^{14}$	$2.1x10^{11}$	$4.3x10^{9}$	$5.2x10^{6}$
^{129}I	$1.7x10^{7}$	$2x10^{-11}$	$6x10^{-8}$	$1.9x10^{9}$	$1.9x10^{9}$	$6.2x10^{5}$	$6.2x10^{5}$
^{99}Tc	$2.1x10^{5}$	$2x10^{-9}$	$2x10^{-4}$	$7.2x10^{9}$	$7.2x10^{9}$	$7.2x10^{5}$	$7.2x10^{5}$
^{90}Sr	28	$3x10^{-11}$	$3x10^{-7}$	$2.0x10^{15}$	$1.6x10^{12}$	$2.0x10^{11}$	$1.6x10^{8}$
^{3}H	12.3	$2x10^{-7}$	$3x10^{-3}$	$2.0x10^{9}$	$1.6x10^{2}$	$1.3x10^{5}$	$1.0x10^{-2}$
TOTAL FISSION PRODUCTS				$2.5x10^{15}$	$1.9x10^{12}$	$2.2x10^{11}$	$1.7x10^{8}$

*Source: ORIGEN (Ref. 37) run for model fuel at 30MW(th)/Mg, 33,000 MWd(th)/Mg burnup.

**Code of Federal Regulations Title 10; 10CFR20.

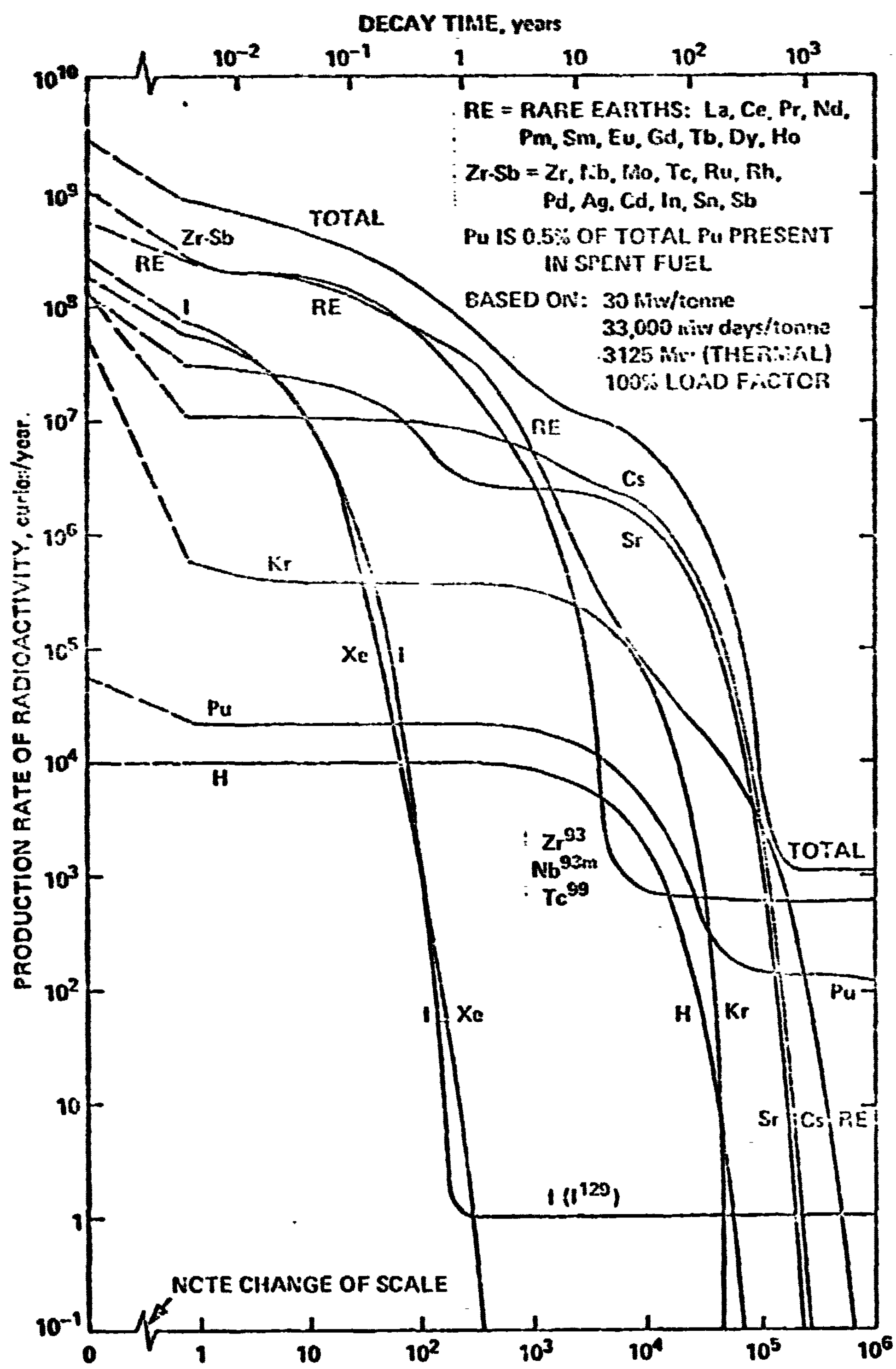
#Volume of air in m^3 to dilute quantity present in wastes from 1 Mg of reprocessed fuel to specified MPC(air).

+Volume of water in m^3 to dilute quantity present in wastes from 1 Mg of reprocessed fuel to specified MPC(water).

EARTH: Total water = $1.4x10^{18}$ m^3; Air to 5.5 km altitude has volume of about $3x10^{18}$ m^3.

FIGURE 3.6

RADIOACTIVITY PRODUCED IN ONE YEAR BY A 1000 Mw(e)
LIGHT WATER NUCLEAR POWER PLANT



SOURCE: PIGFORD, REF. 18

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given to Pu in most literature is due to the greater quantities of Pu in current inventories, the additional amount of handling and shipping it will receive, and common recognition of its existence and properties.

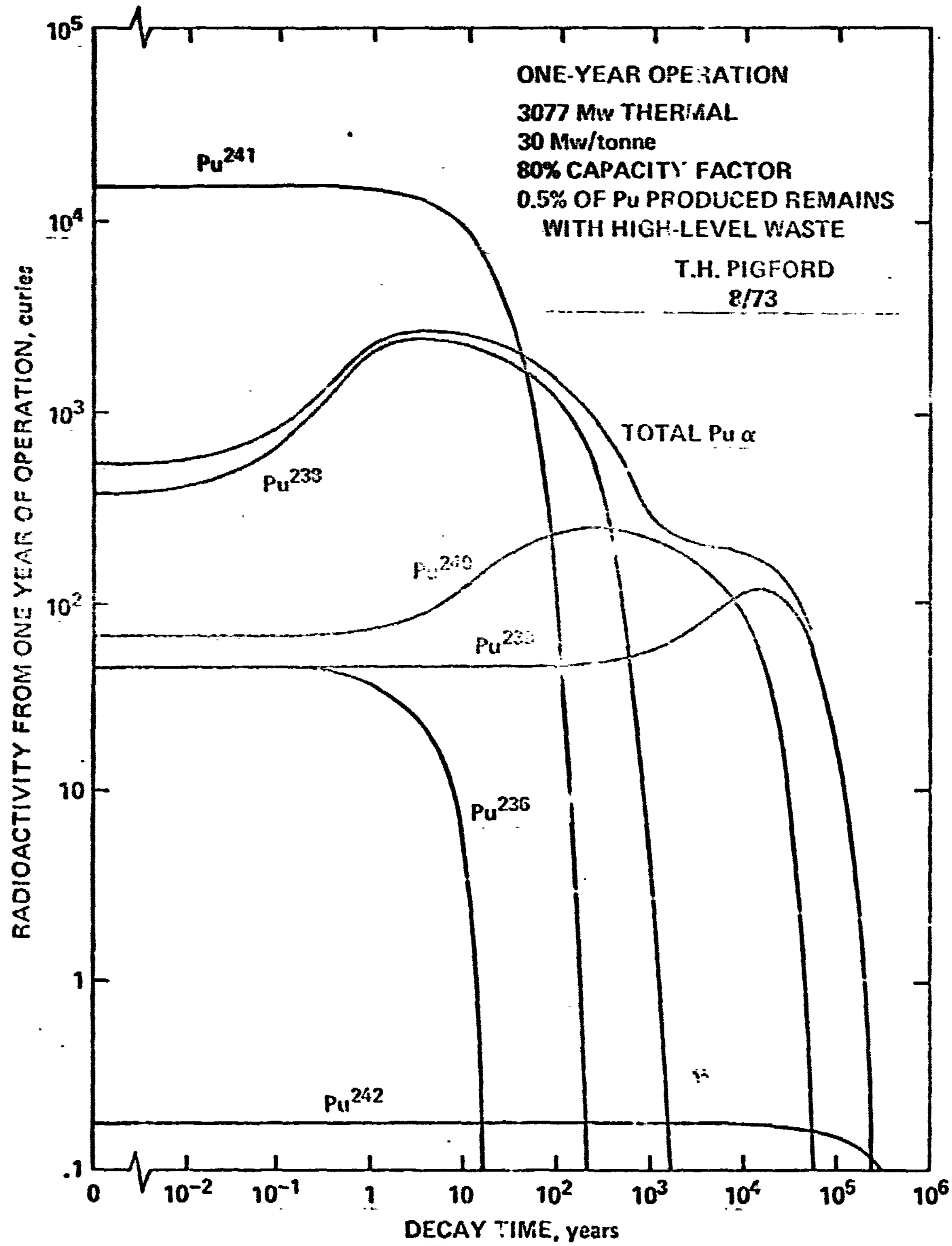
Figures 3.7 and 3.8 are more detailed plots of the transuranics in HLW from annual operation of an LWR fueled with isotopically enriched uranium, for times up to 10^6 years after discharge from the reactor. It can be seen that the Am and Pu dominate the activity for long times. Pu decays by alpha-emission to U, and the two most significant long-lived isotopes, ^{239}Pu and ^{240}Pu decay to ^{235}U and ^{236}U respectively. The latter are also alpha-emitters, but with very long lifetimes; the activity of the Pu decay daughters is therefore not sufficient to appear on these figures.

Figure 3.9 shows the relationship between the various actinides. The leading isotope of Am at first is ^{241}Am, with a half-life of 458 years for alpha-decay to ^{237}Np. The latter is also an alpha-emitter, with a half life of 2.1 x 10^6 years for alpha-decay. A storage time of roughly 10^4 years is needed for the ^{241}Am to decay away; in this case, the combination of original Am activity and daughter decay time is such that the build-up of ^{237}Np does contribute a measurable activity to the wastes. For times approaching 10^6 years or greater, the ^{237}Np will dominate the alpha-activity. However, the ^{237}Np inventory at discharge from the reactor is already quite large, so the incremental contribution from subsequent ^{241}Am decay is small.

The primary contributor at times after the ^{241}Am has decayed away is ^{243}Am, with an 7,950 year half-life for alpha-decay to its short-lived daughter ^{239}Np, which quickly emits a beta and goes over to ^{239}Pu.

Figure 3.7

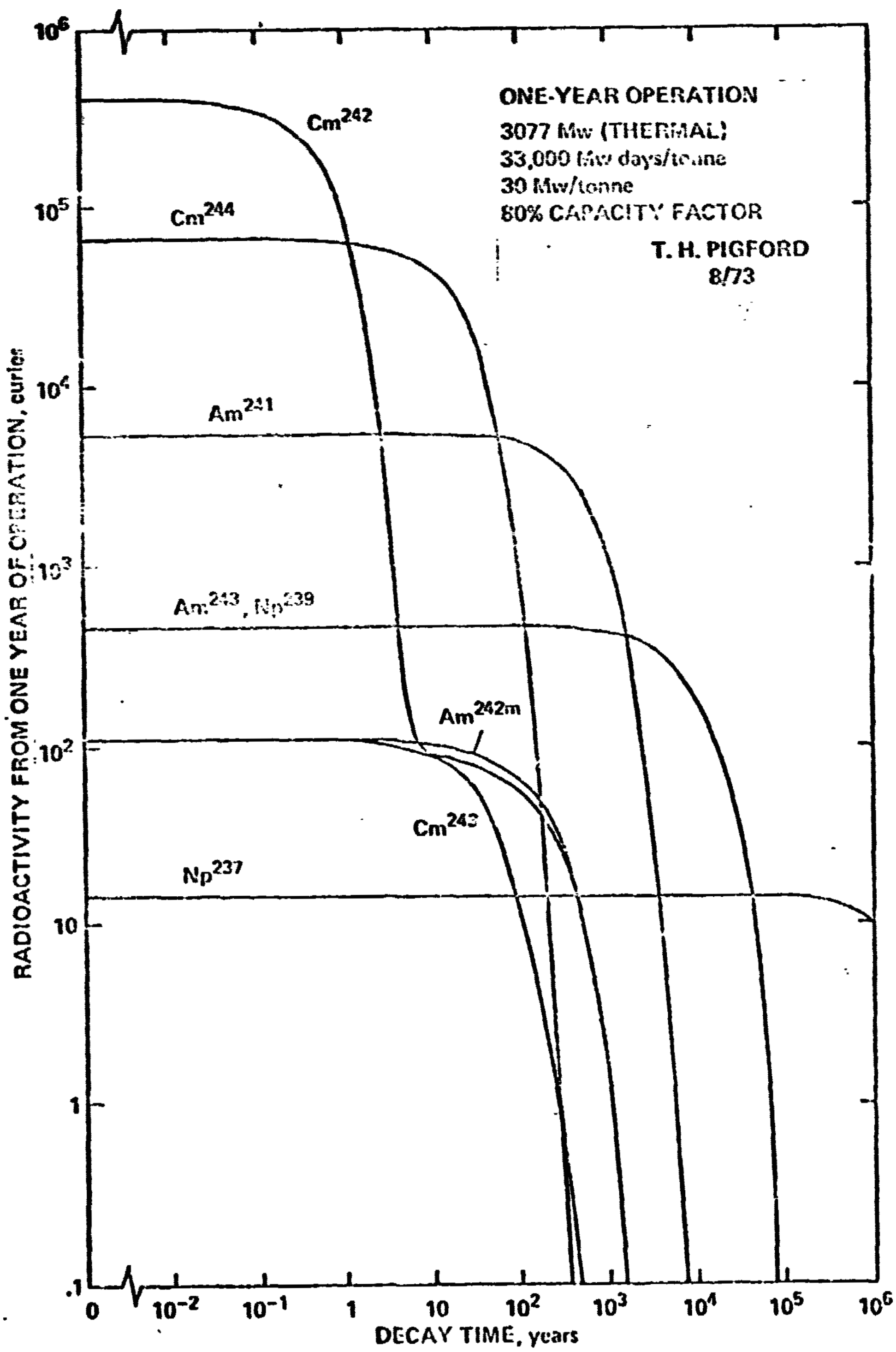
PLUTONIUM IN HIGH-LEVEL WASTES FROM URANIUM-FUELED WATER REACTOR



Source: Pigford, Ref. 39

Figure 3.8

AMERICIUM AND CURIUM IN HIGH-LEVEL WASTES FROM URANIUM-FUELED WATER REACTOR



Source: Pigford, Ref. 39

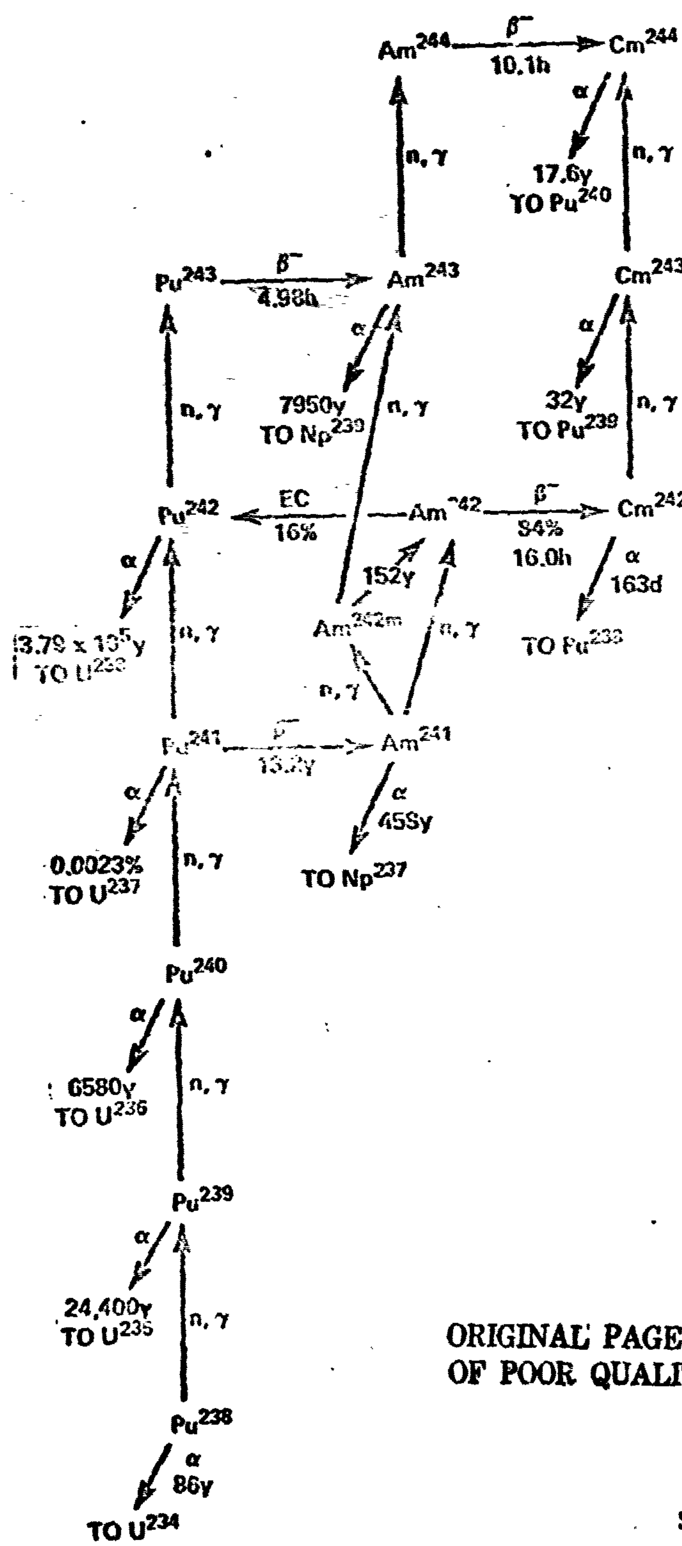
The net result of this decay is the production of additional quantities of 24,400-year half-life ^{239}Pu. Unlike the case of the ^{241}Am decay to ^{237}Np, the net effect here is quite visible as an increase in the ^{239}Pu activity at times of roughly 10^4 years after discharge. As the half-lives of mother and grandaughter are similar, there is only a moderate reduction in net alpha-activity. Storage times greater than 10^5 years are necessary for the roughly equal amounts of ^{239}Pu remaining in the wastes after reprocessing and generated in storage by Am decay to be reduced to near-harmless levels.

The isotopes of Cm are shorter-lived, and decay away in times comparable to fission-product decays. However, the ^{244}Cm plays a double role in the waste management problem. At the time of shipment of the HLW solids, roughly 10 years from discharge, the alpha-activity is dominated by the ^{244}Cm. The potential for (alpha-neutron) reactions with Fluorine or Oxygen in the HLW solids requires considerable shielding against the high-energy neutrons produced, and the ^{244}Cm is the primary source. Furthermore the buildup of 6580-year half-life ^{240}Pu is due to the alpha-decay of ^{244}Cm. Thus, although long-term waste management concerns focus on the Am and Pu in the HLW, it should be recognized that the role of Cm as the mother of the bulk of the Pu in reprocessing wastes at times greater than 100 years is far from negligible.

In fact, decay-product Pu so dominates the long-term activity of the HLW that increasing the efficiency of Pu extraction from the spent fuel would have little impact. Complete removal of the

Figure 3.9

ACTINIDE CHAINS IN URANIUM-PLUTONIUM FUEL



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Source: Pigford, Ref. 18

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Pu from the HLW at the time of reprocessing would only reduce the Pu alpha-activity at times longer than a thousand years by about one-fifth. Long-term waste management problems are insensitive to the efficiency of Pu removal as long as the fraction going out in the HLW is less than, say, 2%.

Although the mass, activity, and thermal power of the fission products clearly dominates the HLW at the time of production, much of the concern about proper waste management has centered on the alpha-emitting actinides. There appear to be two reasons for this. First, there is less concern over the integrity of waste disposal sites for the thousand year storage times needed for most of the fission product activity to die out. Secondly, when small quantities are ingested or inhaled, the alpha-activity of the actinides presents somewhat of a greater hazard to human health, on a per Curie basis, than does the beta or gamma activity of the fission products.[40] The precise value for this increase in relative hazard depends on the model taken and the assumptions made, but estimates that are many orders of magnitude higher than those used to derive the MPC values listed in Table 3.7 have been made.[41] It is certainly not within our competence or the scope of this report to deal with such matters as the residence time of various isotopes in the human body, which affects the hazard presented by a given rate of radioactive decay, or to attempt to referee the controversy over the toxicity of Pu. We do mention that the hazards we discuss here are not those due to direct radiation from large masses of wastes, but of ingestion or inhalation of released radionuclides. In this context, the concern over the actinides is most certainly warranted.

Most of the controversy presently raging about the toxicity of inhaled Pu arises from the question of localized irradiation owing to the very short range of alpha-particles in tissue. The effects of radiation on an organ are usually estimated by taking the time integrated flux incident upon the organ and dividing by its mass. For beta and gamma radiation, and even more so for energetic neutrons, this assumed distribution of dose over tissue is an accepted procedure, and radiation standards are frequently quoted in terms of whole-body dosage. In models that lead to the very high estimates for Pu toxicity, it is assumed that small particles of Pu, when inhaled, deposit selectively on certain vulnerable places in the lung where they remain for long times. As the range of the alpha-particles is very small, the assumed result is a very high local irradiation of the neighboring tissue. The integrated dose over the tissue volume defined by the alpha range is said to be very much greater than one would expect by dividing the total activity by the entire mass of lung tissue. Thus the concern over the carcinogenic properties of the alpha-emitting actinides.

Of course, it is also true that some of the fission products, such as ^{90}Sr (which deposits in the bone) and the various radioisotopes of iodine (which deposit in the thyroid) are not only fairly mobile in the environment, but selectively deposit in some of the most vulnerable organs of the body.[42] It has been argued that there is little chance that Pu would become available in a form suitable for inhalation even if a waste disposal site should fail, and that excessive attention is being focused on the actinides.[43] It has also been pointed out that the distinction between the thousand-year storage times needed for the fission products and the far longer storage needed for the actinides, a distinction which is a natural one in physical terms, is hardly a meaningful one on the time scale of social or political predictability.

Nevertheless, this natural separation of the HLW components according to half-lives has stimulated the idea of separating the long-lived actinides out of the waste stream and dealing with them separately. The HLW would then be separated into two streams. One, consisting primarily of the fission products, would be hazardous "only" for times less than one or two thousand years. This component could then be stored or disposed of in terrestrial geological sites in which we have a high degree of confidence over the times involved. The relatively small remnent with long half-lived actinides and some fission products residue would then be a candidate for such "ultimate" disposal methods as transmutation or ejection into outer space.

Partitioning

Processes which would separate the actinides from the fission products in the HLW stream go under the general name of partitioning. Various chemical separation methods by which this might be accomplished have been suggested, although none of them has been proven as yet.[44] It is not clear just where in the reprocessing cycle partitioning might occur. For our purposes, it makes little difference whether this takes place as an integral final step in the reprocessing operation or is performed afterwards on the liquid wastes prior to the solidification. It does appear that once the waste is solidified, there will be no further possibility of partitioning it, owing to the insolubility of presently suggested HLW solids.

The partitioning decision must, therefore, be made fairly early in the history of the reprocessing plants. Alternatively, the prospects for later partitioning might prove so attractive as to convince the NRC to relax the present 5-year rule for HLW liquid conversion to solids so as to let a partitioning operation start up. Another possibility is that the first reprocessing plants (AGNS and Exxon) will not have partitioning facilities, but later plants will. All of these possibilities will, of course, have an effect on the viability and size of the space disposal option. For the purposes of this study we restrict ourselves to two cases: either there is no partitioning at all, or all reprocessing facilities are equipped for partitioning. As can be seen from Fig. 3.5, a decision made no later than about 1990 to retrofit AGNS and Exxon with partitioning facilities would make little difference in the total mass to be disposed of. For only the very small quantities of solid wastes projected for the years 1990-1995 would not be partitioned.

As with other chemical processing procedures, the separation of fission products from the actinides will not be perfect, and some residue will remain.[45] As partitioning is, at the moment, a hypothetical and complex procedure to be undertaken by as yet unidentified processes, we will make no attempt to identify the probable extraction factor for fission products. Given their large thermal power and activity, a very high extraction factor would be necessary to achieve large reductions in package specifications. Previous NASA studies[46] took 99% and 99.9% extraction factors in calculating required package configurations. It would seem to us that even 90% fission product separation would markedly decrease the waste thermal power and mass, resulting in a reduction of perhaps a factor of five or ten in the amount of HLW containing the long-lived components. However, as we are in no position to attempt to recalculate waste packaging for space operations for this set of conditions, we shall deal with them only in terms of rough estimates. We shall also assume that ^{99}Tc is separated as well, and packaged with the other very long-lived wastes.

Pu Recycle

To this point, we have dealt solely with an LWR-U fuel cycle, assuming that the Pu produced in the reprocessing operations is stored away for further use. From our conversations with various officials of ERDA, NRC, and industry, it seems very unlikely that this Pu will ever be treated as waste to be disposed of, although the masses involved are not beyond the range of space operations to deal with.

Should the decision be made to recycle this Pu back into the nuclear fuel cycle, the characteristics (although not the mass) of the HLW would be markedly affected. The decision as to whether or not the recycle of Pu will be allowed is expected sometimes in 1977. The major issue is determining the tradeoff between the increased hazards of a fuel cycle which circulates Pu and the prospects of lower U ore requirements by roughly an additional 10% (compared to recycling only U) and reducing enrichment service demands by about the same amount.[47]

In an all-LWR nuclear energy system such as we have restricted this study to, there will never be enough Pu produced to entirely substitute for enrichment services (that is, by mixing it with only natural uranium). There are several alternative paths by which the PuO_2 could be mixed with UO_2 to augment istoptically enriched fuel. It could be blended in with somewhat less enriched UO_2, either in the entire fuel cycle or in specific reactors. It could be mixed with UO_2 in which the U is either natural, or depleted (from enrichment plant tails), or the slightly enriched U from the reprocessing plant. These mixed-oxide (MOX) fuel rods could be assigned to specific portions of the reactor core, with conventional enriched-U rods making up the bulk. Specific reactors could be identified for the use of MOX rods, while others use only UO_2.

Since we have found it convenient in dealing with other parts of our analysis to make cut estimates similar to those of the GESMO, we shall also assume that the equilibrium MOX fuel cycle will be the one described in both the draft[13] and final[47] versions of that document. The analysis is based on designating a specific number of reactors for MOX fuel use. This number is in turn based on calculating available MOX loadings. It is assumed that the typical reactor using MOX fuel will contain a load of up to 40% MOX fuel pins, with the remainder being ordinary isotopically enriched UO_2 pins. The amount of Pu involved in recycle is then calculated. Not all reactors will use MOX fuel. A more precise calculation involving the rate of production of Pu and the rate of expansion of the LWR industry shows that MOX pins will amount to about 11% of the total fuel fabricated ato the year 2000.[47] As we have used amore slowly expanding LWR economy than that assumed in the GESMO, this number is an underestimate for our model.[48] Nevertheless, as the upper limit on this number is certainly less than 15%, and as rate of expansion of reprocessing capability limits

Pu availability, only a small error will be incurred if we also assume the GESMO estimate of 11% for this report. Again, this will allow the use of analyses performed by other groups to fix numbers for our study.

The recycle of Pu will markedly alter the character of the HLW produced as a result of reprocessing MOX fuels. The cyclic re-burn of Pu will alter the isotopic balance towards shorter lived and more active isotopes and greatly increase the quantities of transuranics present as compared with LWR wastes from UO_2 fuels. Figure 3.10 shows the heat release as a function of time after 150-day reprocessing for wastes from UO_2 fuel, equilibrium MOX fuel, and an average mix of 89% isotopically enriched UO_2 and 11% MOX. Table 3.8 lists the quantities and activities of the major transuranics present in the spent fuel just prior to reprocessing, and Table 3.9 shows the major contributors to the heat generation in 10-year aged wastes for these same three fuel mixes.

The assumption made in GESMO and related documents is that the considerably higher heat output and activity of the wastes from MOX reprocessing will not present severe problems if these are mixed back with the wastes from reprocessing ordinary UO_2 fuel, which comprises 89% of the total. There are reasons to doubt the validity of this assumption, which depends to some extent on the way in which the reprocessing plants are managed.[50] Nevertheless, as we are in no position to recalculate the relevant parameters, we will stipulate that an "average waste mix" will occur in practice and not just as a conceptial device.

As can be seen from examining Tables 3.8 and 3.9, the inclusion of 11% of equilibrium recycled MOX fuel dramatically increases both the activity and the thermal power of the transuranics in the HLW stream. Although this

Figure 3.10

APPROXIMATE HEAT RELEASE OF LWR

WASTES AS FUNCTION OF AGE

·Source: Draft GESMO, Ref. 13

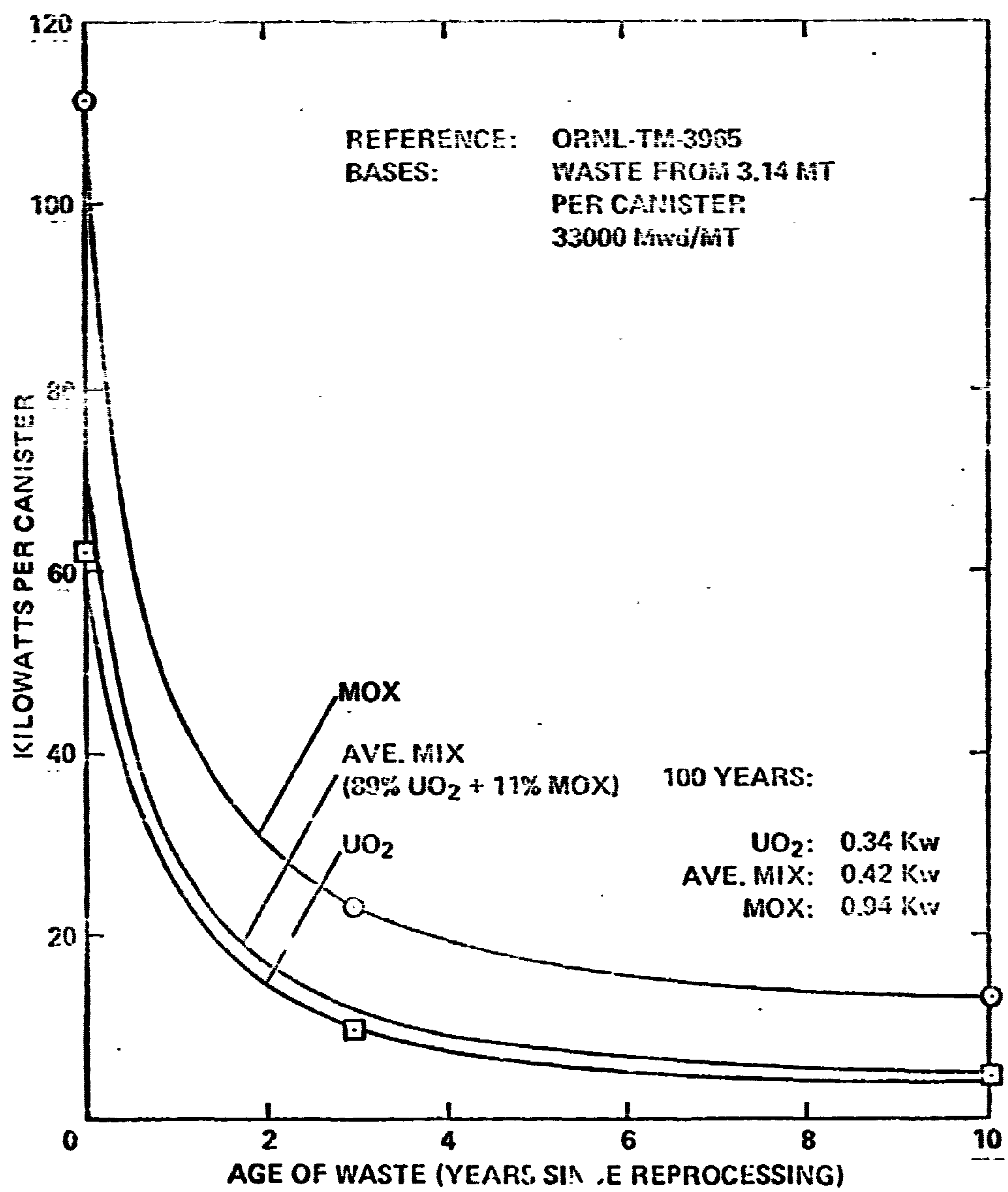


TABLE 3.8

(Source: Draft GESMO, Ref. 13)

ESTIMATED MAJOR TRANSURANIUM COMPOSITION OF SPENT FUEL - WITHOUT AND WITH PLUTONIUM RECYCLE
(BASIS: PER METRIC TON, 33000 MWd/Mg, AGED 150 DAYS)*

Isotope	Enriched UO_2 Fuel			Mixed Oxide Fuel			Average Mix**		
	grams	curies	watts	grams	curies	watts	grams	curies	watts
^{237}Np	480	0.34	0.010	120	0.085	0.0025	440	0.31	0.0091
^{238}Pu	160	2,820	91	1,100	18,900	610	260	4,590	150
^{239}Pu	5,300	323	10	12,000	735	23	6,000	368	11
^{240}Pu	2,200	477	15	8,800	1,940	60	2,900	638	20
^{241}Pu	1,000	103,000	4.3	6,000	608,000	25	1,600	160,000	6.6
^{242}Pu	350	1.38	0.041	4,200	15.2	0.48	770	3.01	0.089
^{241}Am	46	159	5.3	460	1,580	53	92	315	11
^{243}Am	95	18.2	0.67	2,700	51[illegible]	19	380	72.7	2.7
^{242}Cm	5.1	17,000	620	72	240,000	8,800	12	41,500	1,500
^{244}Cm	30	2,400	84	1,700	136,000	4,800	210	17,100	600
F.P.***	28,800	4,200,000	19,000	29,000	4,500,000	21,000	28,800	4,200,000	19,000

*Reference: J.O. Blomeke, C.W. Kee, J.P. Nichols; "Projections of Radioactive Wastes to be Generated by the U.S. Nuclear Power Industry"; ORNL-TM-3965; February 1974; Tables 4.3, 4.6, B-1 and B-2.

**On the basis that about 11% of fuel is mixed oxide fuel, remainder is enriched UO_2 fuel.

*** Fission products are not transuranium elements, but are added for comparison.

TABLE 3.9

(Source: Draft GESMO, Ref. 13)

ESTIMATED HEAT OUTPUT IN HIGH-LEVEL WASTE

(BASIS: 33,000 MWd/Mg, 0.5% LOSS OF PU

TO WASTE AT 150 DAYS, WASTE AGED 10 YEARS)*

Isotope	Watts per Mg of Fuel**		
	Enriched UO_2 Fuel	Mixed Oxide Fuel	Average*** Waste Mix
^{237}Np	0.010	0.0026	0.0092
^{238}Pu	3.0	40	7.0
^{239}Pu	0.050	0.12	0.058
^{240}Pu	0.14	3.9	0.55
^{241}Pu	0.013	0.078	0.020
^{242}Pu	0.00020	0.0024	0.00044
^{241}Am	5.4	53	11
^{243}Am	0.66	19	2.7
^{242}Cm	0.26	6.5	0.95
^{244}Cm	57	3200	400
F.P.+	1010	855	993
Total	1080	4200	1400
WATTS PER CANISTER†	3400	13000	4400

* Calculated from J.O. Blomeke, C.W. Kee, and J.P. Nichols; "Projections of Radioactive Wastes to be Generated by the U.S. Nuclear Industry, ORNL-TM-3965"; February 1974; Tables 5.8, 5.10, B-1, and B-2.

** In addition to the radionuclides listed, about 5000 grams of uranium and 20 to 200 grams of other actinides are in the waste. These contribute 1 to 40 watts.

*** On the basis that fuels processed are about 11% mixed oxide, remainder is enriched UO_2 fuel.

\+ Excluding ^3H, noble gases and 99.9% of halogens. These are removed from waste during reprocessing.

† On the basis of 2 ft^3 of waste per metric ton, 6.28 ft^3 per canister.

only incrementally increases the problems of handling undifferentiated HLW, the waste heat is no longer so completely dominated by the fission products. The activity and thermal power of the fraction containing the actinides will increase by about an order of magnitude. If partitioning is also to take place, this has quite serious implications for projections of space disposal operations. In particular, thermal power has been a limiting factor in package design, with a great deal of the mass of hypothetical disposal packages devoted to high thermal conductivity material to convey internal heat to the package surface.

As was the case for the U-fueled LWR, the longest-lived component of the HLW is the Pu produced by Cm decay. We may compare the effects of the larger Cm inventory in MOX spent fuel with that of U fuel by noting that the inventory of Pu in spent MOX fuel is, according to GESMO, about a factor of six greater then in spent U fuel. As the increase in the ^{244}Cm inventory alone is about ten times greater than the increase in α-active Pu, the sensitivity of waste management reprocessing plant efficiency is lowered slightly. Of course, one must remember that according to the GESMO, only 11% of the reprocessed fuel will be MOX. Yet, the waste management problem will be dominated by this fraction. As an example of cross-sensitivity, the total amount of Pu activity in MOX HLW at times greater than 10^3 years will not be much altered by increasing the amount of Pu going into the HLW (from the MOX alone) from 0.5% to 3%. Yet, the additional MOX Pu in the average HLW mix at times greater than 10^3 years will equal the total contribution from the 89% of the wastes that come from the reprocessing of isotopically enriched U fuel.

It must be emphasized that the numbers quoted in GESMO and reproduced here are for <u>equilibrium</u> Pu recycle. One reason for choosing 1990 as the test year for the GESMO was that this was the earliest year for which an equilibrium recycle could be established. In this study, we would have to defer the equilibrium year to 2000 in order to be consistent with out other assumptions. It does, however, take many years to phase in the Pu recycle, and many more years before equilibrium concentration of actinide isotopes is achieved in the reprocessing plants. Over most of the period being considered in this study, the annual industry-wide "average mix" of HLW would start at the values for UO_2 fuel alone and rise to MOX fractions above the 11% "average" for the GESMO equilibrium cycle.[51] This introduces yet another variable into any attempt to perform a time-sequence analysis of any waste disposal operation, but is particularly serious for methods such as space disposal where partitioning is also assumed to occur.

Table 3.10 lists the radioactivity and thermal power of 10-year aged partitioned HLW with and without Pu recycle for several degrees of partitioning efficiency. It should be noted that the total activity that arises from these wastes is not solely due to direct effects from the listed isotopes. The solidified HLW will contain other elements which may interact with primary decay activity to produce other secondary radiation.

For instance, one of the most severe problems for the shipping of alpha-emitters such as ^{244}Cm is the production of high energy neutrons by (alpha,n) reactions. These reactions occur when the alpha particles from transuranic decay interact with the nuclei of light elements such as

TABLE 3.10

ESTIMATED ACTIVITY AND THERMAL POWER OF 10-YEAR AGED HIGH-LEVEL WASTES FROM REPROCESSING

(Basis: 33,000 MWd(th)/Mg, 0.5% loss of Pu,U to wastes, reprocessed at 150 days)

Partitioning Efficacy*	WATTS/Mg of SPENT FUEL#			CURIES/Mg of SPENT FUEL#		
	Enriched UO_2	Mixed Oxide	Average Mix**	Enriched UO_2	Mixed Oxide	Average Mix**
0	1080	4200	1400	3.2×10^5	3.6×10^5	3.3×10^5
90%	170	3435	520	3.4×10^4	1.3×10^5	6.6×10^4
95%	120	3390	470	1.8×10^4	1.1×10^5	4.9×10^4
99%	80	3360	430	5.6×10^3	1.0×10^5	3.7×10^4
99.9%	70	3350	420	2.7×10^3	9.9×10^4	3.5×10^4
99.999%	70	3350	420	2.4×10^3	9.9×10^4	3.5×10^4

#Excluding trititum, halogens, and noble gases. These are assumed to be removed during reprocessing.

*Degree of fission product removal in chemical partitioning.

**Using GESMO (Ref. 13) assumption of 11% MOX, 89% enriched Uranium at equilibrium.

oxygen or fluorine and release neutrons: for example, the interaction of an alpha with ^{16}O to create ^{19}F plus a neutron. This can markedly increase the neutron emission rate. ^{239}Pu, for instance, has a spontaneous emission rate of about 2×10^{-2} n/sec per gram, whereas $^{239}PuF_4$ has a rate of 4.3×10^{3} n/sec per gram, and $^{239}PuO_2$ a rate of 4.5×10^{1} n/sec per gram. Neutrons from (alpha,n) reactions in Cm in the spent fuel are the primary source for which the casks are neutron shielded.

Conclusion

The numbers derived in this chapter are the basic technical data needed to set up the package and mission design for a hypothetical space disposal program. But they can not be translated into actual mission numbers without further analysis. In Chapter 5 we shall return to these data and combine them with NASA-supplied information on space shuttle technology to generate a set of estimates of mission frequency and package characteristics.

Notes to Chapter 3

1. As of early 1976, costs as high as $1,135 per kw were being quoted. See for example, "Is Nuclear Too Costly?" by R. Stuart, New York Times, October 5, 1975.
2. I. C. Bupp, J. C. Derian, M. P. Donsimoni, and R. Treitel, "Trends in Light-Water Reactor Capital Costs in the United States; Causes and Consequences," Center for Policy Alternatives, MIT, Cambridge, Mass., 1974.
3. P. L. Joskow and M. L. Baughman, "The Future of the U.S. Nuclear Energy Industry," MIT Energy Laboratory Report # MIT-EL-75-006, MIT, Cambridge, Mass., 1975 (unpublished). Case C corresponds closely to Case 6, continued high costs for capital, of this report.
4. Nuclear Power Growth 1974-2000, report # WASH-1139(74), U.S. Atomic Energy Commission, Washington, D.C., February 1974.
5. Creating Energy Choices for the Future, report # ERDA-48, U.S. Energy Research and Development Administration, Washington, D.C., June 1975.
6. A useful summary of contending views is contained in Oversight Hearings on Nuclear Energy-Nuclear Breeder Development Program, Hearings before the Subcommitee on Energy and the Environment, House Committee on Interior and Insular Affairs, Serial 94-16 Part II, U.S. Government Printing Office, Washington, D.C., 1975.

   Given the recently announced timetables for the Clinch River Fast Breeder Test Reactor, and considering the long lead times likely for commercial development if present trends continue, we believe that it is unlikely that there will be any significant installed LMFBR capacity by the year 2000. The first commercial LMFBR would come on line no earlier than 1985. Given the ten to twelve year period before wastes from even this first reactor would be available, the case for space disposal could confortably be reconsidered at the time when LMFBR commercialization on an extensive scale looked probable.

7. Nuclear News, 18, #4, November 1975, at p. 112.

8. Although Gulf-General Atomic has suggested that ERDA pick up the HTGR as an experimental program, such action would be unlikely to revive commercial interest in the HTGR in the next few years. Little, if any, additional HTGR capacity can be expected by the year 2000.

9. Draft Environmental Statement, Light-Water Breeder Reactor Program, report # ERDA-1541, U.S. Energy Research and Development Administration, Washington, D.C., July 1975.

10. T. H. Pigford and K. P. Ang, Health Physics 29, 451 (1975).

11. Ibid.

12. The net nuclear capacity for this scenario is incorrectly stated in Table B-2 of Ref. 5. The correct figure, as quoted in this report, is derivable from Fig. B-4 of the appendix.

13. Draft Generic Environmental Statement on the use of Mixed-Oxide Fuels (GESMO), report # WASH-1327, U.S. Atomic Energy Commission, August 1974.

14. There is some doubt expressed as to whether BWR penetration will remain large enough to assure the 2/3 to 1/3 ratio, as current trends are favoring PWRs. Our model implies a market share for BWRs of about 4 to 5 BWRs per year of the current 1.1 to 1.3 GW(e) size (that is, about 1/3 of 17 GW(e) per year). This is about the minimum number of annual reactor sales necessary to maintain a vendor in the business

for any length of time. We argue that the alternative to this level of BWR sales would be the complete disappearance of General Electric, the only purveyor of BWRs at the moment, from the domestic reactor market. This seems highly unlikely. We anticipate that only two PWR vendors will survive. In any case, these assumptions do not seriously affect our analysis when compared with other assumptions we have been forced to make.

15. Adapted from an unpublished ERDA report meant to update the results of WASH 1139(74) (Ref. 4).

16. See, for example, the discussion in Critical Mass 1, #12, March 1976, at p. 14.

17. D. D. Comey, "Will Idle Capacity Kill Nuclear Power?", Bulletin of the Atomic Scientists 30, #9, (November 1974).

18. T. H. Pigford, "Environmental Aspects of Nuclear Power Generation," Annual Review of Nuclear Science, Vol. 24, 1974.

19. LWR Spent Fuel Disposition Capabilities 1975-1984, report # ERDA-25, U.S. Energy Research and Development Administration, March 1975.

20. There is some confusion in the literature on this point. Ref. 18 states, for instance, that all values quoted for the LWR represent 100% capacity factor, and should be multiplied by the appropriate factor for lower C.F. operation. This is done in Ref. 10 to the extent of multiplying not only effluent and waste figures, but also core size and annual reload so as to maintain annual replacement of 1/3 of the core, but retain full burn at lower C.F. This does not seem to agree with present industry practice. We hold to the assumption that reactors

will continue to have cores sized for possible operation at C.F. as high as 90 to 100%. This would seem to us to be a necessary precondition for achieving an industry-wide value of 70%.

21. There is an excellent discussion of this in Ref. 6. See also, "Reneging on Uranium at Westinghouse," by Reginald Stuart, New York Times, Feb. 1, 1976.

22. The figure of 33 Mg/GW(e)-yr. is, of course, not sensitive to such questions as designed core size or questions of core turnover, nor does it depend on installed capacity for this case. It is also possible that higher fuel burns will be designed for and achieved by the year 2000. In the absence of firm indications to this effect, we omit this possibility from consideration in this report.

23. This algorithm fits ERDA data and projections quite well. It is partly an artifact of the way the capacity for each process is counted and listed as of the end of the calendar year.

24. According to a statement of Mr. F. P. Baranowski before the Joint Committee on Atomic Energy in November, 1975, there are about 500,000 gallons of liquid high-level waste stored at the Nuclear Fuel Services site in West Valley, New York. These are residues of the 630 Mg of fuel reprocessed from 1966 to 1972. There is no solidification facility extant or planned at the NFS site, and the wastes cannot be shipped as liquids under present NRC regulations.

25. At lower fuel burns, less ^{235}U is consumed, and less ^{239}Pu is produced, but the effects are not linear owing to the increased fission of ^{239}Pu as the ^{235}U is consumed. The optimal ratio of fissile Pu production to

fissile U consumption depends upon the design of the reactor, but will occur at burns considerably lower than those considered here. The question of the quite low burns used for production of weapons-grade PU has to do with the isotopic composition, and is of no direct relevance to this study.

26. Draft GESMO, Ref. 13.

27. Ibid.

28. The concentration factor for spent fuel alone is roughly a factor of twenty, but there is also a considerable mass of reprocessing chemicals and other elements in the waste which reduces the overall mass decrease.

29. That is, a sufficiently large volume of liquids could support a self-sustaining chain reaction. While far from being a bomb, which has a very rapid energy release compared to most criticality incidents, the occurrence of such an accident would be quite hazardous, and could lead not only to the extensive destruction of associated equipment, but also to very large releases of radioactivity.

30. Some sources have stated that this plant is to process 2100 Mg/yr. We hold to the estimate of 1500, partly out of conviction, partly for convenience.

31. We do not believe that either NFS or MFRP will contribute to U.S. reprocessing capacity in this time frame. MFRP appears to have been abandoned, and NFS is vacating its license.

32. These might very well be stored and shipped as liquids, which requires active cryogenic refrigeration.

33. Figure 3.4 shows that both AGNS and the Exxon plant would be needed to

close the fuel cycle even for the very low size projected in Case F. It is more likely that, should a decision be made to hold nuclear power down to this level, only AGNS would be operated, probably by the federal government. It would be used to separate out HLW for easier disposal.

34. Code of Federal Regulations, Title 10: Energy, U.S. Government Printing Office, Washington, D.C., January 1972, 10 CFR 50, Appendix F.

35. High-Level Radioactive Waste Management Alternatives, report # BNWL-1900, Battelle Pacific Northwest Laboratories, Richland, Washington, May 1974.

36. For a typical LWR fueled with isotopically enriched UO_2 only, there are about 380 liters of liquid HLW per Mg of fuel burned to the full level of 33,000 MWd(th)/Mg. The constituents of this liquid are estimated to be (in kg per Mg of spent fuel):

	Misc. chemicals	2.4
	NO_3	65
	Fe	1.1
Total reprocessing chemicals		68.5
Uranium, at 99.5% recovery		4.5
Other actinides		0.7
Total fission products		28.8
TOTAL		102.8

37. M. J. Bell, "ORIGEN - The Oak Ridge Isotope Generation and Depletion Code," report # ORNL-4628, Oak Ridge National Laboratory, Oak Ridge, Tennessee, May 1973.

38. This data was compiled from a variety of official publications and reports too extensive to list here. Useful summary discussions may be found in <u>Environmental Radioactivity</u>, by M. Eisenbud, (Academic Press, New York, 1973).

39. T. H. Pigford, "Radioactivity in Plutonium, Americium and Curium in Nuclear Reactor Fuel," a study prepared for the Ford Foundation Energy Policy Project, Dept. of Nuclear Engineering, University of California, Berkeley, Calif., June, 1974.

40. For instance, the International Commission on Radiological Protection recommendations for continuous occupational exposure to unidentified radionuclides in air lists a tolerance of 10^{-17} Ci/m^3 of air if there are no alpha-emitting radionuclides and ^{227}Ac is not present. This drops to 10^{-18} Ci/m^3 if it is not known [illegible], and ultimately down to 4×10^{-19} Ci/m^3 if it is not definitely known that ^{231}Pa, Th, ^{239}Pu, ^{240}Pu, and ^{249}Cf are absent.

41. The most vo al and visible proponent of this point of view has been Dr. J.W. Gofman. See, for example, "The Cancer Hazard from Inhaled Plutonium" CNR Report 1975-1-R, Committee for Nuclear Responsibility, Inc., P. O. Box 332, Yachats, Oregon, 1975, and references therein. It is worth noting that each of the several mechanisms suggested in this report to obtain the final numbers would separately increase the Pu hazard.

42. See Ref. 38.

43. See, for example, B. L. Cohen, "Hazards from Plutonium Dispersal," Nuclear Physics Laboratory, University of Pittsburgh, Pittsburgh, Penn., date unknown: submitted to <u>Radiation Research</u>.

44. A useful discussion of partitioning is contained in Ref. 35.

45. That there may also be some transuranics remaining with the partitioned fission products is a serious problem that has received little attention. Unless the degree of separation is such that only a very tiny residue remains, partitioning will not make space disposal more attractive.

46. R. E. Hyland et al., "Feasibility of Space Disposal of Radioactive Nuclear Waste," NASA Lewis Research Center, National Aeronautics and Space Administration, Cleveland, Ohio, 1974.

47. Final Generic Environmental Statement On the Use of Recycle Plutonium in Mixed Oxide Fuel in Light Water Cooled Reactors (GESMO), report NUREG-0002, U.S. Nuclear Regulatory Commission, August 1976.

48. Furthermore, the GESMO figure as quoted here is for an equilibrium fuel cycle in which there is adequate reprocessing capacity for the annual production of spent fuel--both UO_2 and MOX.

49. That is, the slower expansion rate used in Case C means there will be fewer new reactors to fuel each year than in GESMO. As Pu is derived from past reactor operation, this slower growth rate increases the percentage of Pu available for fuel fabrication compared to annual total demands.

50. In conversations with representatives of AGNS, agency officials, and other knowledgeable persons, it was stated that AGNS does have the inherent capacity to reprocess MOX as well as isotopically enriched fuel. However, some reluctance to actually reprocess MOX was indicated. It is possible that only one of the proposed reprocessing facilities would be assigned to handle MOX, which presents additional radiological

and safeguarding problems to the reprocessor. Under these conditions, the "average mix" of nuclear wastes is of relevance only when calculating aggregate properties of the waste. However, ERDA or NRC could require that MOX wastes be mixed uniformly with UO_2 wastes before solidification *if* each reprocessing plant is assigned a distributed share of MOX to reprocess.

51. Even after the ratio of Pu to U in the fuel cycle reaches equilibrium, the isotopic composition of the Pu and other transuranics does not come to equilibrium values until the Pu has been recycled several times.

CHAPTER 4

PRECONDITIONS FOR THE EXISTENCE OF HIGH-LEVEL WASTES IN A FORM SUITABLE FOR SPACE DISPOSAL TO BE A USABLE OPTION

Perhaps the most puzzling aspect of discussion concerning space disposal operations, both in popular writing on waste management and in general overviews by industry and government representatives, is the frequent failure to distinguish it sharply enough from terrestrial methods of waste management. As is shown in Fig. 4.1, detailed analyses by ERDA and its contractors clearly separates transmutation and space disposal from other methods.[1] But their distinction is not made primarily on the basis of end result, that is, the degree to which the wastes are removed permanently from any possibility of re-entering the environment. It is made on the basis of the prior conditions that must be met before transmutation and space disposal can be implemented. Commercialization of these procedures would require the existence of an industry or government capability for the removal of virtually the entire inventory of fission products from the high-level waste stream, leaving behind a product that is very rich in the long-lived actinides. Without such waste

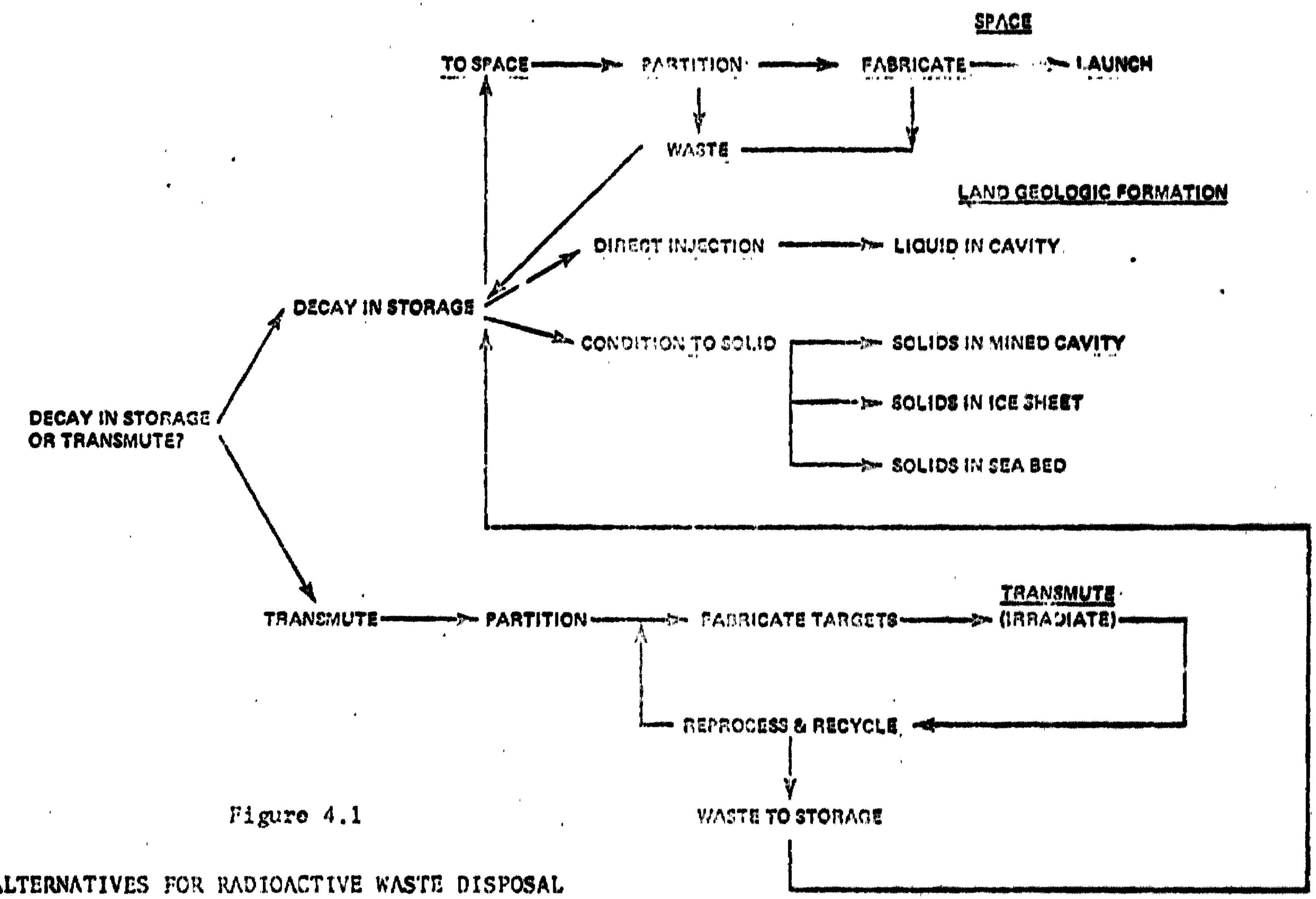


Figure 4.1

ALTERNATIVES FOR RADIOACTIVE WASTE DISPOSAL

BASIC ALTERNATIVES LOGIC

WOOD

partitioning, space disposal and transmutation are held to be too expensive and difficult to implement in any foreseeable time frame.

Terrestrial schemes, on the other hand, have in common a great deal of flexibility in material handling capabilities, however outlandish and expensive they may be. Most, if not all, of these methods would require only moderate incremental additional investments to adapt to a wide variety of masses, densities, and characteristics of HLW. Even the unprocessed spent fuel might be easily dealt with. This is not true for space disposal.[2] What interests us here is the question of whether those isotopes whose toxicity and lifetimes are considered to present a serious enough hazard to warrant such high-technology handling are likely to be well enough separated from the far greater mass of spent fuel by commercial processes so as to present a total mass that is within the reach of projected NASA technology.

Without going too deeply into the precise technical details, which will be discussed elsewhere in this report, we assert that the net mass of very long-lived transuranics is small enough over the 1975-2000 time period considered that present and projected NASA launch vehicles are capable of removing them permanently from the planet. There still remain two important conditions that must be satisfied before space disposal can be considered a viable option. There must be sufficient separation of the fission products and other materials from the transuranics so that the mass, thermal power, and activity of the resultant package remains within the scope of possible launch capacity: the various separation processes must be efficient enough to guarantee that all but a very small remnant of the transuranics actually end up in the final disposal package. If the first condition is not met, the program is not possible; if the second condition is not met, the program is not sensible.

A minimum requirement for simultaneous fulfillment of these two conditions is the existence of a fuel reprocessing industry capable of expanding rapidly enough to deal with all of the commercially produced spent fuel. It would make little sense to initiate space disposal operations to handle the output of a reprocessing capacity projected to be inadequate to reduce the nation-wide spent fuel inventories if these spent fuels are to be stored in retrievable or temporary storage facilities. High-level wastes are separated, not created during reprocessing. The hazardous isotopes are no less dangerous when diluted in the spent fuel.

In accordance with the previously stated assumption of this study, and with statements made by ERDA, NRC, and industry personnel, we will not treat Pu separated from the spent fuel during reprocessing as candidate wastes for ultimate disposal. But presently considered HLW disposal methods are not being shaped entirely by concern over the Pu remnant in the HLW. Assuming sufficient reprocessing capacity to deal with all spent fuel, about 98% of the Pu produced in commercial nuclear power reactors will either be stored in (presumably federal) Pu repositories or recycled back into the power system as MOX-LWR or LMFBR fuel. Of the remaining 2% or so, only one-fourth will be in the HLW.

The question of what happens to the remaining 1 1/2 % of the Pu is a critical one for establishing the "sensibility" of space disposal, even if concern about Pu is not the determining factor in selecting an ultimate disposal system. By one widely accepted set of estimates,[3] the distribution of Pu losses in the GESMO fuel cycle would be as follows: 0.5% would go to

HLW as is commonly stated, but another 0.5% would be lost to low and intermediate-level wastes at the reprocessing plant. Additional losses of 0.5% to transuranic-contaminated wastes will occur both at the mixed-oxide conversion plant and at the fuel fabrication facility. For all except the HLW, the Pu will be mixed in with large quantities of other material. These Pu-contaminated wastes would, therefore, not be candidates for other than terrestrial disposal. We anticipate that this loss problem would be entirely confined to Pu, and take for granted the statements that "all" of the other transuranics would be extracted as HLW, with no loss to other wastes.[4]

It would be most convenient if we could establish a fixed bench-mark for the nuclear industry to specify the level of efficiency in keeping track of Pu at which space disposal is "sensible" according to our criterion. Specific conditions, however, vary according to the cycle chosen and the relative weights assigned to short-term versus long-term concerns. The as yet unresolved question of the relative hazard of inhaled alpha-emitters versus biologically mobile fission products also becomes a factor. We may at least begin to examine this problem by treating three separate possibilities for the nuclear fuel cycle: a "throw-away" cycle in which all spent fuel is treated as waste; a "stow-away" cycle in which Pu is kept available for possible reuse at a later time; and a complete recycle economy à la GESMO [5]

The "throw-away" cycle presents two important cases. It is possible that spent fuel will never be reprocessed. In this case, it is unlikely that space disposal will prove to be possible at all unless the size of the nuclear power industry is very small or NASA develops an extremely heavy-lift vehicle. There is also a small, but finite, possibility that reprocessing would be promoted primarily for the purpose of facilitating waste management. In this case, all Pu would follow the HLW.[6] There would still be recycle of U, lowering the demand for mining and enrichment services slightly, particularly if the nuclear industry continues the present relatively poor fuel burns. At present low capacity factors, considerably more ^{235}U remains in the spent fuel than in our analysis of Case C.[7] As no attempt would be made to extract Pu, it would follow the HLW with roughly the same efficiency as the other transuranics, and there would be little Pu left outside the HLW stream. The Purex process for extracting U from spent fuel, as used by AGNS and other proposed reprocessing plants, is said to produce U of such high purity that there is no concern over fractional losses of transuranics to the recycled U. Although space disposal may not be possible for this case, it would certainly be sensible from the point of view of removing all of the long-lived alpha-emitting transuranics.[8]

The "stow-away" cycle predicates the existence of reprocessing capacity adequate for the separation of all of the Pu in the spent fuel. Again, there are two primary cases of interest for waste management. In the first, the Pu is separated and stored, but the HLW are not further processed before disposal. In terms of possibility of the HLW, this case is very much like the second case discussed for the "throw-away" cycle. Table II-3 shows that almost all of the Pu activity at short times is from beta-emitting ^{241}Pu with a 13.2-year half life.[9] This may be treated as if it were a fission product for our purposes. Therefore, the removal of Pu from HLW that already contains large quantities of fission products makes very little difference for waste management as far as total mass and activity are concerned.

However, if we stipulate an 0.5% loss of Pu to other than HLW at the reprocessing plant, an appreciable fraction of the original alpha activity will remain in lower level wastes. For the fraction lost to the low level wastes, the alpha activity over time will decrease simply according to the half-lives of the various isotopes of Pu. The alpha activity in the HLW is more complicated to analyze. At shorter times--less than a thousand years or so--the activity of Am and Cm dominates. However, as these decay away the decay products are usually alpha emitters as well.[10] At very long times, the HLW activity is dominated by the Pu produced by decay of Cm and Am. Details vary according to the type of fuel, and will be discussed as they become relevant. For the all-U LWR cycle being examined here, the result is that the alpha activity due to the 0.5% of the Pu that remains in the low level wastes will be roughly 1% that of the total alpha activity of the HLW at 10 years after reprocessing, about 5% at 1000 years, and will continue to increase to about 25% of the activity in the HLW at 10.000 years or more.[11] This poses a serious question as to the efficacy of space disposal for this case. The purpose of space disposal is to markedly reduce the inventory of alpha-emitting isotopes at very long times. But the Pu lost to other-than-HLW will be disposed of terrestrially. Unless such losses can be reduced, it is not clear that space disposal of the remainder is sensible.

The second case for the "stow-away" cycle is the possible separation of the shorter-lived fission products from the longer lived transuranics and ^{99}Tc by partitioning. This much reduces the mass and activity of that portion of the HLW that contains the transuranics, and makes them more amenable to space disposal. We shall discuss in Chapter 5 the various degrees of efficacy in removing fission products and the effect this has on space disposal operations.[12] For the present, let us merely suggest that about an order of magnitude reduction in necessary throw weight can be achieved.

Obviously, this markedly increases the possibility of space disposal for the case under consideration. But the effect of Pu losses to other than HLW argues even more strongly against sensibility. To see this, let us examine the effects of partitioning over both the thousand year and the greater then 10,000 year time scales. Over the first thousand years, the activity of the long-lived transuranics will be less than the beta-activity of ^{241}Pu, and far less than the activity of the fission products. In terms of total activity, nothing much is to be gained over the first thousand years or so by partitioning and disposing of the long-lived fraction. As with the previous case, the alpha-activity of the 0.5% Pu loss will be small compared to that in the HLW, rising to about 5% at 1000 years. But space disposal is not generally held to address waste management over this time scale, even if concern over transuranics dominates. Over the far longer time scale of Pu decay, an appreciable fraction of the total alpha activity will remain on earth in low level wastes. By our previous calculation, only 4/5 of the long-lived alpha-emitting transuranics will be available to be disposed of by the combination of partitioning and space disposal.

As this second case for the "stow-away" cycle is the first relatively possible one discussed, it is worth pausing to estimate the level of Pu management that would increase its sensibility. Properly, an absolute criterion for the total inventory of long-lived alpha emitters should be established, dependent on the type of wastes in which they are contained and the method of disposal of those wastes. If such a number (or set of numbers) could be devised, more accurate estimates of the required accounting of Pu in low level wastes could be constructed. Even to attempt such an estimate is beyond the scope of this study.

What we can suggest is a necessary (but not necessarily sufficient) criterion based solely on the percentage of the long-lived alpha emitters that can be removed from the planet by the combination of partitioning and space disposal. It would be remarkable if the total alpha curies to be produced by the nuclear industry would be just exactly at the level where the removal of 80% of the activity would lower the risk to acceptable levels. Barring such an unlikely combination of circumstances, we propose that any high-technology operation such as partitioning and space disposal should at least reduce the long-lived alpha inventory by two orders of magnitude.

For the case under consideration, we note that the effect of the decay of Cm and Am in the HLW at long times is to increase the inventory of Pu by roughly a factor of four over that portion attributable to the original fraction of Pu at reprocessing.[13] If 99% of the alpha activity at times longer than a few thousand years is to go off with the HLW, this imposes a condition that only about 1/25 of the amount of Pu in the HLW at the time of reprocessing be lost to other wastes, corresponding to about 0.02% of the total amount of Pu in the spent fuel.[14]

Industry sources have suggested that the loss of Pu to other than HLW is in fact avoidable. Automated machinery to detect segments of sheared fuel rod that are sealed off into their insoluable cladding would help, and does not appear to present insurmountable technical difficulties. Careful attention to the cleaning and design of all equipment that comes into contact with Pu might prevent other losses. It is not clear whether these fixes will be affordable or possible at the required level, but there is a clear need for some reduction in the incidental loss of Pu at the reprocessing plant in any case. Otherwise, it would hardly seem worthwhile to expend enormous sums of money and talent to devise any irreversible method for disposal of HLW. Whether the required reduction from 0.5% to 0.02% that we have set up as a criterion can be accomplished is a more difficult question to answer.

The third major scenario we shall consider is the GESMO Pu recycle case. As in the GESMO, 89% of the fuel in this cycle is ordinary istopically enriched U, while 11% is MOX made up of Pu and natural U oxides. The mass and total activity of the HLW are not much changed. As was shown in Table 3.8, the overall inventory of alpha-emitting transuranics, will be considerably increased owing to the very high transuranic content of equilibrium MOX spent fuel. For times on the order of a hundred years or less, the alpha activity will be dominated by ^{244}Cm, which is increased by a factor of seven in the average waste mix over the inventory for an equivalent all-U fuel cycle. At longer times, this drops to roughly a factor of four, primarily from decay product Pu.

The initial inventories of Pu in the average mix HLW will not increase greatly. ^{239}Pu will be up by about 10% and ^{240}Pu by about 1/3. More importantly, the act of recycling the Pu will entail greater losses to other than high level wastes. If we take present estimates as reliable, then in addition to the 0.5% loss at the reprocessing plant, another 0.5% will be lost at both the oxide-conversion facility and at the fuel fabrication plant. Thus 1.5% of the Pu in spent fuel will be lost to low and intermediate level wastes as compared to the 0.5% that follows the HLW. The absolute activity of this "lost" Pu will be about four times what it would be for an all-U fuel cycle.[15]

Paradoxically, although the absolute loss of Pu will increase, the relative efficacy of space disposal for removal of long-lived alpha activity will remain almost unchanged from the previously considered "stow-away" cylce. This is because the much larger Am and Cm inventories in the MOX spent fuel markedly increased the quantities of decay-product Pu produced in the average waste mix. At very long times, only about one-fifteenth of the ^{239}Pu and ^{240}Pu in the HLW will be undecayed remnants of the original Pu inventory at reprocessing.[16] The greater part of the Pu present (and these two isotopes dominate the long-term alpha activity) will be from decay of ^{244}Cm and ^{243}Am. Looking at the different decay times and total activities of the two isotopes of Pu, we may estimate that the total alpha-activity in HLW from an "average mix" of wastes in the GESMO equilibrium MOX recycle case will increase by roughly a factor of four over the all-U case.[17] Therefore, the ratio of Pu in the HLW to Pu remaining in lower level waste streams is, at long times, about the same as for the "stow-away" cycle even though the amount of Pu lost in this way is increased by a factor of four.

The arguments made for the previous case can then be simply extended to the Pu recycle case, with the caveat that the increased quantity of Pu in other than HLW may place an even higher performance criterion of Pu accounting when absolute activity standards are established. On the previous assumption that the minimum condition for space disposal to make sense is that it reduce the amount of Pu (at long times) by two orders of magnitude, the requirement now becomes that losses of Pu to lower level wastes be held to 0.02% at <u>each</u> of the three steps--reprocessing, oxide production, and fabrication--or to 0.06% total for all processes.[18]

The implications of these scenarios for space disposal can perhaps be seen more clearly if we reorganize them in terms of the handling given to the HLW before delivery. The three possible cases for HLW handling are the disposal of undifferentiated spent fuel (which is not really HLW in the usual parlance), HLW from reprocessing without further treatment, and the transuranic-containing fraction of partitioned HLW.

Space disposal of undifferentiated spent fuel would be possible only under a very restrictive set of conditions that kept the entire nuclear industry very small indeed. However, as virtually all of the long-lived nuclear wastes are contained in the spent fuel, space disposal would be completely effective in removing them permanently from the environment.

Space disposal of HLW from reprocessing would be achievable if only a fraction of the spent fuel were reprocessed to extract Pu--for instance to generate fuel for an experimental breeder reactor program. However, a great deal more Pu would remain in the unprocessed spent fuel than would appear in the HLW. The 5% of the spent fuel that remains would contain ten times the amount of Pu that would follow the HLW. Even if Pu were not extracted, 99% of the spent fuel would have to be reprocessed to achieve the desired reduction of Pu inventory. Therefore, reprocessing of <u>all</u> spent fuel is a minimum precondition for the use of <u>any</u> expensive, high-technology waste disposal procedure to be sensible.

If Pu is not extracted in reprocessing, but follows the HLW, no further conditions need be met. When Pu is extracted, whether to be stored for future use or for immediate application, an additional sensibility criterion is imposed by the losses of Pu to other than high level wastes at various stages. If our minimum condition for the application of expensive, high-technology waste disposal is accepted--that is, a reduction in Pu inventories in total wastes by two orders of magnitude--then present estimates of 99.5% efficiency in retaining Pu during process handling would have to be improved to 99.98% without Pu recycle and 99.94% overall with it.

Assuming that the partitioning of HLW would result in no additional loss of Pu or other alpha-active wastes to other than the concentrated transuranic-containing fraction, the sensibility criterion given above are not changed. However, the greatly reduced mass and activity of this long-lived fraction would make space disposal operations practicable over a much wider range of installed nuclear capacity.

The case discussed in most previous studies of space disposal is that of partitioned HLW. This satisfies the primary considerations of technical possibility. From the discussion above, it may be seen that technical criteria alone are necessary, but not sufficient, for determining the desirability of space disposal operations. The possibility of achieving required levels of performance in reprocessing, Pu accounting, and partitioning must be determined before the probability that any high-technology exotic method of nuclear waste management will be usable and effective can be estimated. Given the present state of knowledge concerning the processes involved, an accurate determination is not possible. We can only [illegible] generic estimates based on extrapolations of present practices and predictions by others as to achievable levels of performance in the next few decades.

At the present time, there is no commercial reprocessing capacity operating in the United States. The only operational reprocessing plant, NFS in West Valley, New York is shut down at the present, ostensibly to expand its capacity and upgrade equipment.[19] According to the operators, the capacity of NFS is being increased to about 750 Mg of spent fuel per year. Official accounts, however, play down the technical and political factors that resulted in the closing of this plant. Despite ERDA estimates, in GESMO and other documents, that NFS would resume operations sometime in 1978-1982, NFS has now withdrawn its plans and is attempting to vacate its license.[20] Accordingly, we have dropped NFS from further consideration in this study. The MFRP facility constructed by General Electric in Morris, Illinois has been virtually abandoned. This plant was designed around an "aquaflor" process that had marked differences from the usual Purex process. This process had never been used on a commercial scale, and GE experienced great difficulties in process operation and plant design that were inherent in the construction of the process stages at MFRP. A very large investment would be required to modify the plant so as to obtain successful operation, and the combination of time and money required are such that GE will apparently abandon MFRP rather than trying to modify or correct it.[21]

In our view, then, the only committed reprocessing facility in the United States at this time is the AGNS plant in Barnwell, South Carolina. This plant is also beset by a number of issues that must be resolved before it becomes fully operational.[22] The profitability of AGNS has been called into question by many sources. The NRC will not make its decision on the conditions under which Pu recycle will be allowed until 1977, and the AGNS operators are reluctant to open the plant until Pu recycle is allowed. Solidifed waste facilities have not even been designed at this time, and the method used for solidification has not yet been agreed upon. There is some question as to whether AGNS will be allowed to start up before the waste solidification issue is settled. As doubts and delays multiply, there has been increasing concern over whether ERDA should take over AGNS itself and operate it as an experimental facility to help resolve some of the questions as to reliability, operation, and profitability before private industry commits itself to the construction of additional plants.[25]

The only other tentative facility at the moment is the still unsited Exxon plant. It is very doubtful that Exxon would initiate construction on this plant until some of the difficulties with AGNS are cleared up. It is certain that only successful and profitable operation of AGNS would induce other private companies to consider the construction of the additional reprocessing capacity that would be required to close the back end of the nuclear fuel cycle and reduce inventories of spent fuel.

From the point of view of this study, however, the decisions that would enable the complete reprocessing of all spent fuel that is a precondition for the use of expensive, high-technology waste disposal operations to be a sensible method for HLW are independent of whether or not space disposal is considered to be the most desirable method. Other considerations are far more important. The details of waste management at these plants, however, cannot be independently determined by other considerations without seriously interfering with any supposedly independent decision on HLW disposal.

Partitioning is still, at this time, a hypothetical process even on an experimental scale. There have been several studies that have examined the technical feasibility of reprocessing operations,[24] and they have generally indicated that a considerable amount of research will have to be done before commercial process flow charts can be designed. This situation is unlikely to change so long as current disinterest in partitioning is maintained. Neither ERDA nor industry has funded research on partitioning at a very high level. Should an ample supply of technical support and funding be supplied, together with an impetus at the agency level to demonstrate partitioning within a fixed time, these evaluations would be obsolete. There is, however, little indication that they would do so. There would be no reason to construct a partitioning facility if terrestrial geologic disposal is held to be adequate.

If traditional approaches to waste management continue to be followed in the future, it is very improbable that the other preconditions for space disposal operations will be met either. There is no profit to be had from waste management, and therefore no incentive to do other than meet necessary regulatory requirements. Although it may be presumptuous for us to assume that we can forecast more accurately than industry or governmental personnel, it would seem most probable that at least the AGNS plant will ultimately solidify the HLW into a glass, either by the French process or by comparable U.S. processes. This would preclude any possibility of subsequent redissolving and partitioning, but, as we have pointed out, there is no reason to partition unless a decision to dispose of HLW by a method requiring partitioning has already been chosen. The additional requirement that Pu be kept out of the lower level waste streams to an accuracy of 0.02% or better would entail considerable additional engineering and costs. Only a prior decision to restrict transuranic disposal to a method (such as space disposal or transmutation) that removes it from any chance of ever re-entering the environment would even lead to consideration of such tight accountability for Pu losses.

It is, therefore, not correct to merely estimate the probabilities that the necessary preconditions will be met and from these try to project the likelihood that space disposal operations will be both possible and sensible. As long as waste management continues to be treated in this manner, as more the tail than the "back-end" of the nuclear fuel cycle, only as much time, money, and effort as are required for the solidified HLW to meet regulatory minimum requirements will be expended. This will effectively foreclose a number of options for the management of nuclear wastes that might be most desirable on other grounds.

<u>If a high-technology option such as space disposal is to be selected, then the other portions of the fuel cycle that have an impact on the applicability and efficacy of the chosen method must also be altered to facilitate it.</u> To return to our examples, if the nuclear industry is to be very small and the use of Pu held to be undesirable, a selection of space disposal as a desirable method would entail the construction of the necessary reprocessing plant to separate HLW from other components of the spent fuel even if recycle of the U was economically unprofitable.

For the perhaps more likely case of an extensive LWR economy with Pu recycle, a decision to dispose of the long-lived transuranics by space operations would require the fulfillment of the previously mentioned conditions of complete reprocessing, high Pu accountability, and partitioning of all HLW. All of these steps should properly be considered to be part of the waste disposal operation. Just as the GESMO takes into account all portions of the nuclear fuel cycle for computing the value and efficacy of recycling Pu, a proper statement of the possibilities for nuclear waste management must include all other operations that might have to be performed at other steps in the cycle to ensure the value and efficacy of the method under consideration.

The questions, then, are these: What is the probability that the set of decisions that would have to be made to facilitate space disposal operations would in fact become properly linked and, if so, how probable is it that the consequent decision would favor space operations? At the moment, the probability that either one of these questions would be answered affirmatively appears to be very small indeed. This does not necessarily imply that no further attention should be paid to consideration of space disposal. Concern over the disposition of HLW is rising markedly as inventories and projections increase and public concerns become more clearly articulated. Over the next few years, it is possible that, on grounds other than cost-effectiveness or maximum simplicity, the space disposal option and other high-technology methods will be looked at far more closely, with an eye to altering the operation of other parts of the fuel cycle to facilitate such operations. The great danger is that the linkages between the several operations will not be acknowledged soon enough to prevent an irreversible commitment to a facility that is not capable of performing at the level required. This could foreclose the options even as they are being considered.

It does appear unlikely that space disposal would ever become a selected method for managing nuclear wastes unless there were a deliberate and conscious social decision to permanently remove the wastes from all possibility of ever re-entering the biosphere at any time in the future. Such a decision is not to be taken lightly, nor will it be.

But even if this decision were to be seriously considered, there are a number of specific questions that would need to be answered before the impacts of such a program could be estimated: What are the operational hazards and risks? What would the social, radiological and political consequences of full-scale operation be given a fixed set of probabilities for operational risks? What would the social and economic costs be? These questions are not limited solely to the space operation itself. As we have mentioned earlier, space disposal cannot be implemented without also creating the necessary appurtenances and supporting institutions to modify the fuel cycle so that the actinide portion is separated out efficiently and effectively. As time passes and the components of the fuel cycle are increasingly committed for the sake of short-term goals and determined by available and well-understood technology, the possibility of having the choice of space disposal available if it is wanted will increasingly be pre-empted. Large capital investments in waste handling and processing equipment, large political commitments to defend the selected waste management system, and large inventories of solidified high-level wastes that can no longer be adequately redissolved for partitioning would all be irreversible steps along a path that is not compatible with space disposal. If the decision to keep the space option open is not taken within the next ten years or so, while there is still a window for a wide range of waste management choices, we must ask whether space disposal is likely to remain even a possible option.

For the remainder of this study, we shall assume that a decision to opt for space disposal has been properly made, and that the preconditions listed have been met. The next step is to assess the impact of a space disposal operation that is technically possible and radiologically sensible.

Notes to Chapter 4

1. Alternatives for Managing Wastes From Reactors and Post-Fission Operations In the LWR Fuel Cycle, Report ERDA-76-43, U.S. Energy Research & Development Administration, Washington, D.C., 1976.
2. Space disposal operations are particularly sensitive to HLW thermal power as well as radioactivity, owing to the necessity of protecting the integrity of the re-entry capsule in the case of an abort. We shall return to this subject in Section IV of this report.
3. T. H. Pigford, "Radioactivity in Plutonium, Americium and Curium in Nuclear Reactor Fuel," a study prepared for the Ford Foundation Energy Policy Project, Dept. of Nuclear Engineering, University of California, Berkeley, California, June, 1974.
4. In the Purex process, both the U and the Pu are extracted at very high purities. The only other primary output of the process is the high-level waste stream. A flow chart for this process indicates that the loss of transuranics to other than the HLW stream will occur only for Pu, and the Pu losses will be incurred only because of the subsequent handling it receives.
5. Draft Generic Environmental Statement of the Use of Mixed-Oxide Fuels (GESMO), report # WASH-1327, U.S. Atomic Energy Commission, Washington, D.C., August, 1974.
6. Only the Uranium would be extracted in the Purex process for this case. But as this comprises the bulk of the spent fuel, mass reductions of about an order of magnitude would still be achieved compared to unprocessed spent fuel.

7. For instance, at an 80% burn, corresponding to 26,400 MWd(th)/Mg, one third of the original ^{235}U inventory would remain, corresponding to an enrichment of about 1.1%. At currently achieved capacity factors of between 50% and 60%, roughly one-half of the ^{235}U would be discharged in the spent fuel. This would correspond to an enrichment of about 1.65% for the recovered U. Source: ORIGEN code run for model Diablo Canyon reference fuel at 30 MW(th)/Mg, 3.3% enriched U fuel.

8 Of course, there will be associated losses of various isotopes of Uranium from the various U handling facilities. However, the number of alpha-curies produced is quite small. Presumably, fuel hold-up times will be sufficient for the shorter-lived beta-active isotopes of U to decay away.

9. See also K. J. Ang, "Quantities of Actinides in Nuclear Reactor Fuel Cycle," Ph.D. Thesis, Department of Nuclear Engineering, University of California, Berkeley, California, April, 1975.

10. A rather complete discussion of the decay modes of the several actinide species is given in Chapter 3 of this report.

11. At these long times, Plutonium is the dominant contributor to the HLW activity. For times longer than 10^6 years, of course, the longest-lived components of the waste, such as ^{237}Np will dominate, but by this time the total activity in the wastes is quite low.

12. Perhaps a more important consideration will ultimately turn out to be the degree of removal of the transuranics from the fission product fraction of the partitioned wastes. Throughout this report, we assume that these losses are negligible, and do not contribute to the losses of Pu or other alpha-emitters to terrestrially-stored wastes. Should

the partitioning process involve a significant amount of loss of transuranics, the efficacy of space disposal would have to be reconsidered.

13. For a graphic display of the growth of Pu activity in HLW, see Pigford, op. cit. The estimate here is based on the following draft GESMO estimates per Mg of 150-day aged spent UO_2 fuel at 33,000 MWd(th)/Mg assuming 0.5% of the Pu follows the HLW:

^{239}Pu	24,400 yrs	26.5 gms	
^{243}Am	7,950 yrs	95 gms	(to ^{239}Pu via ^{239}Np)
^{240}Pu	6,580 yrs	11 gms	
^{244}Cm	17.6 yrs	30 gms	(to ^{240}Pu).

14. Obviously the calculated fraction is not the same for all times. We have performed this calculation as follows. At the time of reprocessing, assume that for every 1000 Ci of Pu that goes to the HLW, 40 Ci are lost to low-level wastes. At the time when the Pu in the HLW peaks owing to decay of Am and Cm, the alpha activity due to Pu will be equal to that of a mass of Pu which had an activity of 4000 Ci at the time of reprocessing and the same isotopic composition as the Pu in spent fuel.

15. At least for that period where ^{240}Pu activity dominates. At times longer than 10^5 years, ^{239}Pu dominates and the activity will be increased by a factor of about 3.3.

16. This estimate is based on the GESMO "average mix" estimates per Mg of 150-day aged spent fuel, assuming 11% MOX and 89% UO_2, at 33,000 MWd(th)/Mg assuming 0.5% of the Pu follows the HLW:

^{239}Pu	24,400	yrs	30 gms
^{243}Am	7,950	yrs	380 gms
^{240}Pu	6,580	yrs	15 gms
^{244}Cm	17.6	yrs	210 gms

17. Compare the Pu inventories in notes 13 and 16 above.

18. As in note 14, we use Pu activity in the HLW at the time when decay Pu from Am and Cm peaks to establish an equivalent quantity of Pu at the time of reprocessing.

19. Nuclear Fuel Cycle, a report by the Fuel Cycle Task Force, report # ERDA-33, U.S. Energy Research and Development Administration, Washington, D.C., March, 1975.

20. Letter from N.R. Werthamer, Chairman of New York State ERDA to R. C. Seamans, Jr., Administrator, U.S. ERDA, November 30, 1976.

21. Nuclear Fuel Cycle, ibid.

22. Wall Street Journal, Feb. 17, 1976, at p. 1.

23. J. G. Phillips, "Nuclear Report/Fuel cycle problems come back to haunt industry," National Journal 8, 268 (1976). Also see Ref. 22, ibid.

24. J. W. Bartlett et al., Feasibility Evaluation and R&D Program Plan for Transuranic Partitioning of High-Level Fuel Reprocessing Waste, report #BNWL-1776, Battelle Pacific Northwest Laboratory, USAEC, Richland, Washington, November, 1973.

PART II

THE ROLE OF THE NASA SPACE SHUTTLE PROGRAM IN WASTE MANAGEMENT

INTRODUCTION TO PART II

In Part II of the study, we examine the technical, policy, and public environments in which a space disposal program would operate. Part I laid down the preconditions for space disposal to be given consideration as an option. Part II examines the conditions that would have to be met for successful program operation. These conditions are not limited to the technical and operational management of the shuttle program, over which NASA has at least some direct control. If the hypothesized shuttle-based space disposal program is to achieve its goal of markedly reducing terrestrial inventories of long-lived nuclear wastes, the rest of the nuclear fuel cycle must be technically adjusted and managed to those ends. Both industry and government policies and regulatory climate would have to be compatible with the requirements of space operations. Public confidence in the ability of NASA to prevent accidents, and public willingness to accept them if they occur, would be needed. We argue in this part of the report that, in the present industry, government, climate, these conditions are unlikely to be met.

Chapter 5 introduces the space shuttle technology developed by NASA as it applies to conceptual space disposal programs. Mission profiles and waste packaging design are adapted from previous NASA studies. The management of the nuclear fuel cycle is shown to have a major effect on the needed launch rate for the assumed space disposal technology. As this is not determinable, we choose to establish three cases: rising to 10, 100, or 1000 launches per year by the year 2000. These bracket the range of choices, from low enough to be easily fitted into projected shuttle program growth to large enough to throw a major strain on the entire U.S. aerospace industry.

Chapter 6 parallels Chapter 5, but examines the needed program "software"--the resource, institutional, and management requirements for a successful program. Resources needed are human and industrial, as well as mineral. Although we had neither the time nor the resources ourselves to survey the shuttle production requirements closely enough to try to identify "bottlenecks"--areas that are likely to restrict program expansion at the required rate of growth--we generically identify a set of problems that are likely to occur. Shifting a program from an experimental one based on a few vehicles to one of large scale entails expansion at a very rapid rate. Physical resources needed may not be expandable at that rate. Perhaps more critically, organizations and institutions are not well suited either for high growth rates (going to scale) or for rapid shifts from highly stimulating experimental programs to repetitive high-volume ones (going to routine). Even if physical and industrial resources could be provided to handle program growth, problems of organizational growth might prove insurmountable at the required levels of institutional performance.

It is not only difficult, but impossible with any degree of accuracy, to predict policy, regulatory, and public reactions to a future space disposal program. What we have done in Chapter 7 is to examine the past history of institutions that have dealt with waste management in some capacity. From this history, we can infer what institutional issues and regulatory milieus are likely to occur in the near future, based on extrapolation of program histories and directions. Similarly, we examine in Chapter 8 the two extant public attitude surveys that have been performed on public responses to nuclear waste management and attempt to draw from these some conclusions about future public attitudes towards space disposal. Necessarily, the accuracy of such an extrapolation diminishes as it is projected further into the future. The trend, however, appears to us to be quite clear. Unless there are major alterations in the goals and purposes of governments and the public, space disposal is unlikely to find a hospitable climate for operation.

CHAPTER 5

THE SPACE DISPOSAL OPTION USING THE SHUTTLE

Introduction.

Disposal of long-lived nuclear wastes in outer space can be an attractive idea if the goal of waste management policies is irreversibly to remove these wastes from all possibility of re-entering the human environment. Two major issues need to be considered in determining the utility of current or projected NASA-developed capabilities for effectively removing the bulk of the long-lived wastes: whether the program will have the capability to deal with the masses involved for a reasonable mission profile; and whether such operations can be performed at a level of reliability that would lead society to determine that the risks involved would be reasonable and acceptable. We defer the issue of safety adn reliability to the next section, and address here primarily the issue of the adequacy of present and near-future NASA capabilities for dealing with the wastes at the levels currently predicted.

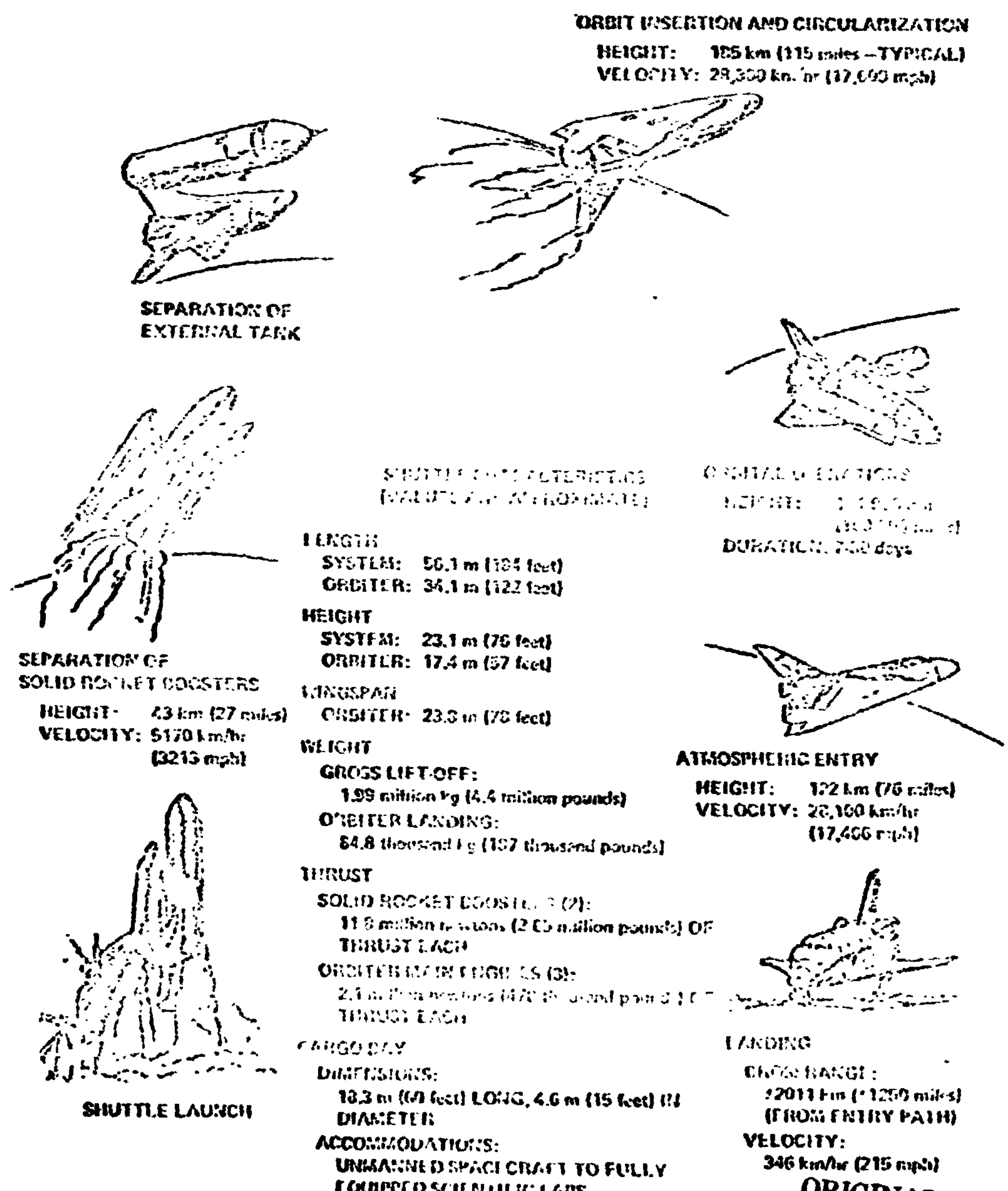
In the absence of technical aid and advice from NASA technical personnel, we are unable in a limited study such as this to examine possible future capabilities and equipment, or independently to assess presently available programs. We rely for our technical information primarily on two NASA reports, one dealing with passive waste containers[1] and one on using the waste heat for a thermally driven ion-propulsions system,[2] that assume the lift vehicle to be the space shuttle as currently designed. We also draw extensively on Section 8 of BNWL-1900,[3] and ERDA-sponsored overview of high-level waste management alternatives.

The baseline technical assumption for this study is that the manned space shuttle as currently planned will be used to implement any chosen method for space disposal of nuclear wastes, and that the only acceptable mission profile is solar system escape on a direct trajectory rather than via Jupiter swing-by.

Figure 5.1 shows a typical launch-to-landing sequence for the space shuttle. The launch vehicle is to be boosted off the pad by two solid-fueled motors that are subsequently dropped for later recovery while the orbiter continues its mission on the expendable external fuel tank. Once the shuttle is orbited, any desired payload can be deployed from the cargo bay. The payload can either perform its own mission or be left in orbit to await further payload deliveries for assembly of a composite vehicle. Figure 5.2 shows how a waste package might be mounted in and deployed from the shuttle orbiter. The orbiter is capable of some orbital maneuvering, and can be used to retrieve a malfunctioning package prior to the separate initiation of the package propulsion system. Upon completion of its mission, the manned orbiter returns to a landing site on Earth.

Figure 5.1

PROFILE OF SHUTTLE MISSION



Each Shuttle orbiter can fly a minimum of 100 missions and carry as much as 29,484 kg (65,000 pounds) of cargo and up to 4 crew members and 6 passengers to orbit. It can return 11,515 kg (32,000 pounds) of cargo to earth.

After reviewing the analysis performed in BNWL-1900, we agree that the only missions that would provide appropriate safety against orbital degeneration are direct solar impact and direct solar system escape. Table 5.1 summarizes the considerations used in deciding among the various missions. Of these two, solar impact is discarded as being too expensive, as the fuel required for such large values of Delta-V (the incremental velocity that must be given to an orbiting package by its propulsion system to achieve the indicated trajectory) would greatly reduce the vehicle payload and thus markedly increase the number of launches required and the associated cost. Although this is sufficient reason for rejection of the solar impact mission, we also point out that several of the persons we discussed space disposal with expressed concern that a nuclear waste package on a solar impact trajectory would volatilize before being captured and drawn in by the sun's gravitational field, and that the solar wind might then push the gaseous cloud of hazardous materials back into the Earth's orbit. All of the projected missions will have to take place in the plane of the planetary orbits to take advantage of the orbital velocity of the Earth. The additional costs of operating out of the orbital plane are prohibitive.

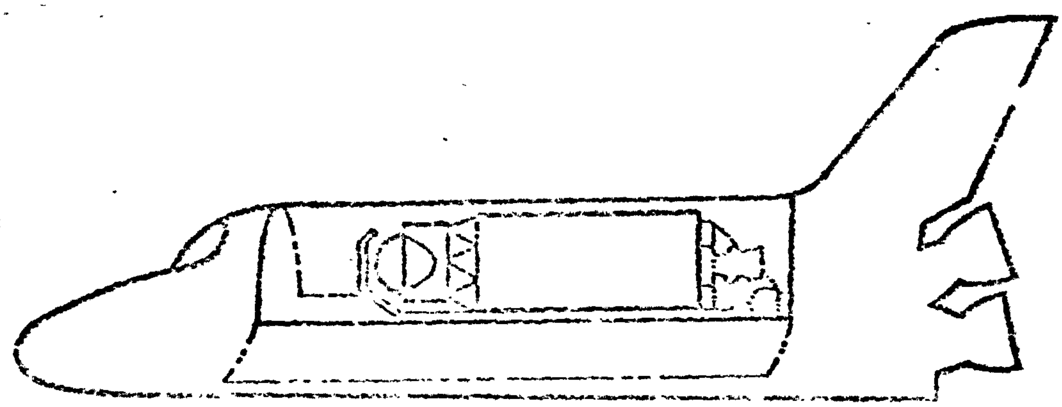
The NASA-Hyland Study.

The major study on the use of the shuttle for the disposal of nuclear wastes has been that performed by the NASA-Lewis Research Center and compiled by Robert E. Hyland.[1] We refer to it throughout as the NASA-Hyland study without derogating the role played by the other participants.

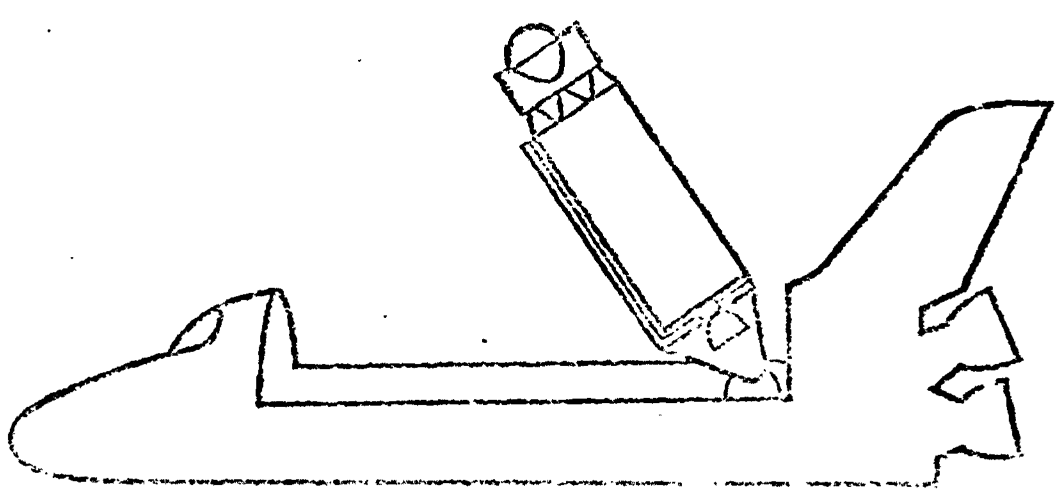
In this study, it was assumed that the wastes would be encapsulated by a method that provided adequate shielding to protect the orbiter crew

Figure 5.2

SPACE SHUTTLE ORBITER WITH NUCLEAR WASTE PACKAGE AND TUG



(a) MOUNTED IN CARGO BAY.



(b) READIED FOR DEPLOYMENT.

Source: BNWL-1900

TABLE 5.1

CONSIDERATIONS FOR VARIOUS SPACE DESTINATIONS

Destination	Delta-V, km/sec	Advantages	Disadvantages
High-Earth Orbit	4.11	Low Delta-V Launch any day Passive waste package Can be retrieved	Long-term container integrity required. Orbit lifetime not proven.
Solar Orbits Via: Single burn beyond Earth escape	3.65	Low Delta-V Launch any day Passive waste package	Longer-term container integrity required. Earth re-encounter possible (may not be able to prove otherwise). Abort gap past Earth escape velocity.
Circular Solar Orbit	4.11	Low Delta-V Launch any day	Long-term container integrity required. Orbit stability not proven. Requires space propulsion system. Abort gap past Earth escape velocity.
Venus or Mars Swingby	4.11	Low Delta-V	Long-term container integrity required. Limited launch opportunity (3 to 4 months every 19 to 24 months). Requires midcourse systems. Need space propulsion or have possibility of unplanned encounter.
Solar System Escape: Direct	8.75	Launch any day Passive waste package Removed from solar system	High Delta-V Abort gap past Earth escape velocity.
Via Jupiter Swingby	7.01	Removed from solar system	High-Delta V. Limited launch opportunity (2 to 3 months every 13 months). Requires midcourse systems. Abort gap past Earth escape velocity.

TABLE 5.1 cont'd

Destination	Delta-V, km/sec	Advantages	Disadvantages
Solar Impact:			
Direct	24.08	Package destroyed Launch any day Passive waste package	Extremely high Delta-V. Abort gap past Earth escape velocity. Not possible with present vehicles.
Via Jupiter Swingby	7.62	Package destroyed	High Delta-V. Limited launch opportunity (1 to 2 months every 13 months). Requires midcourse guidance systems. Abort gap past Earth escape velocity.

Note: Delta-V is the incremental velocity required to leave a low-earth orbit.

An abort gap is a short time period wherein a controlled abort of the mission cannot be accomplished if the flight is off-course.

(Source: BNWL-1900).

and security against aborts and other accidents including a re-entry by the unprotected waste-containing capsule. Major components of this proposal are shown on Fig. 5.3. This is a shuttle/tug/tug mission, requiring two shuttle orbiter launches for every waste package propelled to solar escape. The first mission places a reusable tug into orbit for supplying the major escape propulsion, and the second carries an expendable tug and waste package. A typical waste disposal mission would have the following sequence of events:

1. Launch shuttle #1 to parking orbit.
2. Deploy reusable tug to rendezvous.
3. Launch shuttle #2 to parking orbit.
4. Expendable tug and attached waste package deployed to rendezvous.
5. Ma[illegible]r tugs and dock in tandem.
6. Reusable tug supplies initial propulsion and returns to shuttle #2
7. Expendable tug injects waste package to solar escape trajectory.

A representative nuclear waste package for this mission is shown in Fig. 5.4.

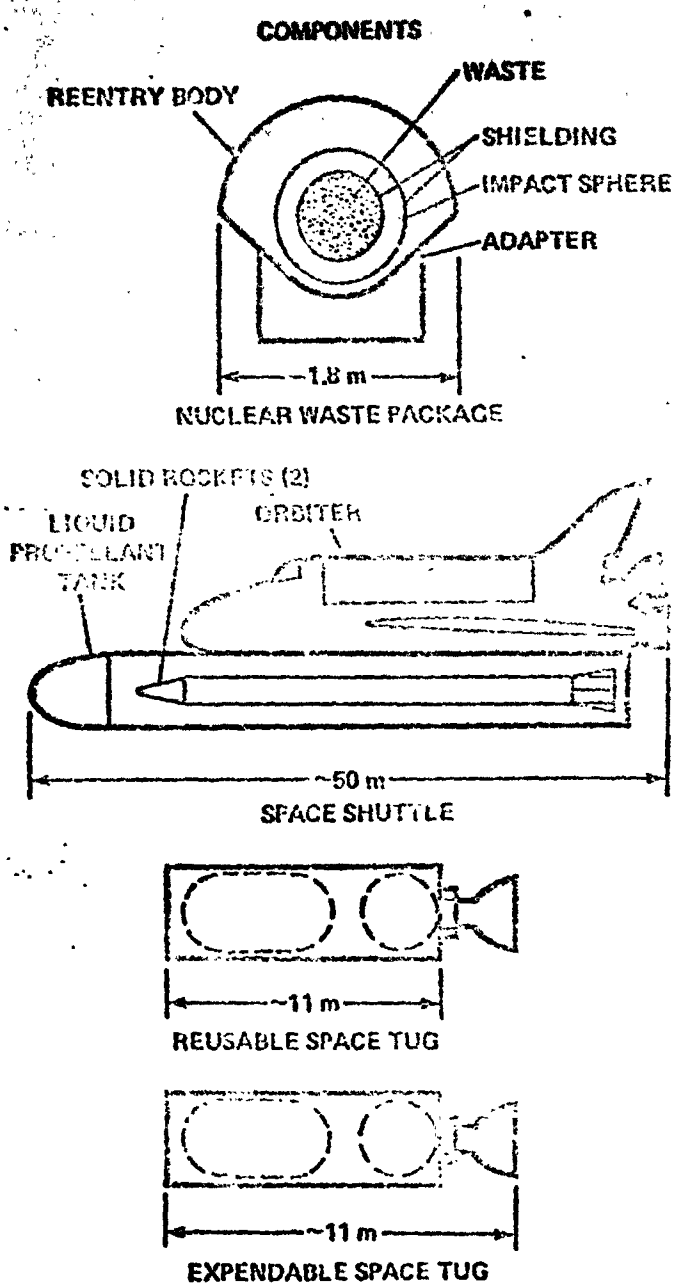
For the package shown, which has a waste payload of about 200 kg. for solar escape, it is assumed that the high-level wastes are partitioned, and that only 0.1% of the fission products follow the actinides into the space disposal processing. The remainder of the high-level wastes, consisting primarily of the fission products, are to be disposed of on earth by geological methods. As discussed in both the NASA-Hyland study and in BNWL-1900, it appears to be impracticable to dispose of the great bulk of the unpartitioned solidified reprocessing wastes. The three cases for potential use of the space disposal option discussed in BNWL-1900 were:

Case 1: Dispose of the bulk of the reprocessing wastes, solidified and encapsulated as borosilicate glass.

Figure 5.3

COMPONENT WEIGHTS FOR NUCLEAR WASTE DISPOSAL MISSION.

Required for mission: one shuttle carrying resuable space tug, and another shuttle carrying expendable space tug and nuclear waste package.



COMPONENT	WEIGHT, kg
NUCLEAR WASTE PACKAGE:	
WASTE (ACTINIDES PLUS 0.1 PERCENT FISSION PRODUCTS)	200
SHIELDING (LiH, W, MATRIX)	1,995
IMPACT SPHERE	640
REENTRY BODY (HEAT SHIELD)	410
ADAPTER	120
SPACE SHUTTLE:	
ORBITER (DRY WEIGHT)	68,000
LIQUID PROPELLANT AND TANK	737,000
SOLID ROCKETS	1,030,000
REUSABLE SPACE TUG:	
PROPELLANT WEIGHT	23,500
BURNOUT WEIGHT	2,900
EXPENDABLE SPACE TUG:	
PROPELLANT WEIGHT	22,000
BURNOUT WEIGHT	2,900

Source: BNWL-1900

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Case 2a: Dispose of actinides only, with fission products separated out to within 1.0% by partitioning.

Case 2b: Dispose of actinides only, with fission products separated out to within 0.1% by partitioning.

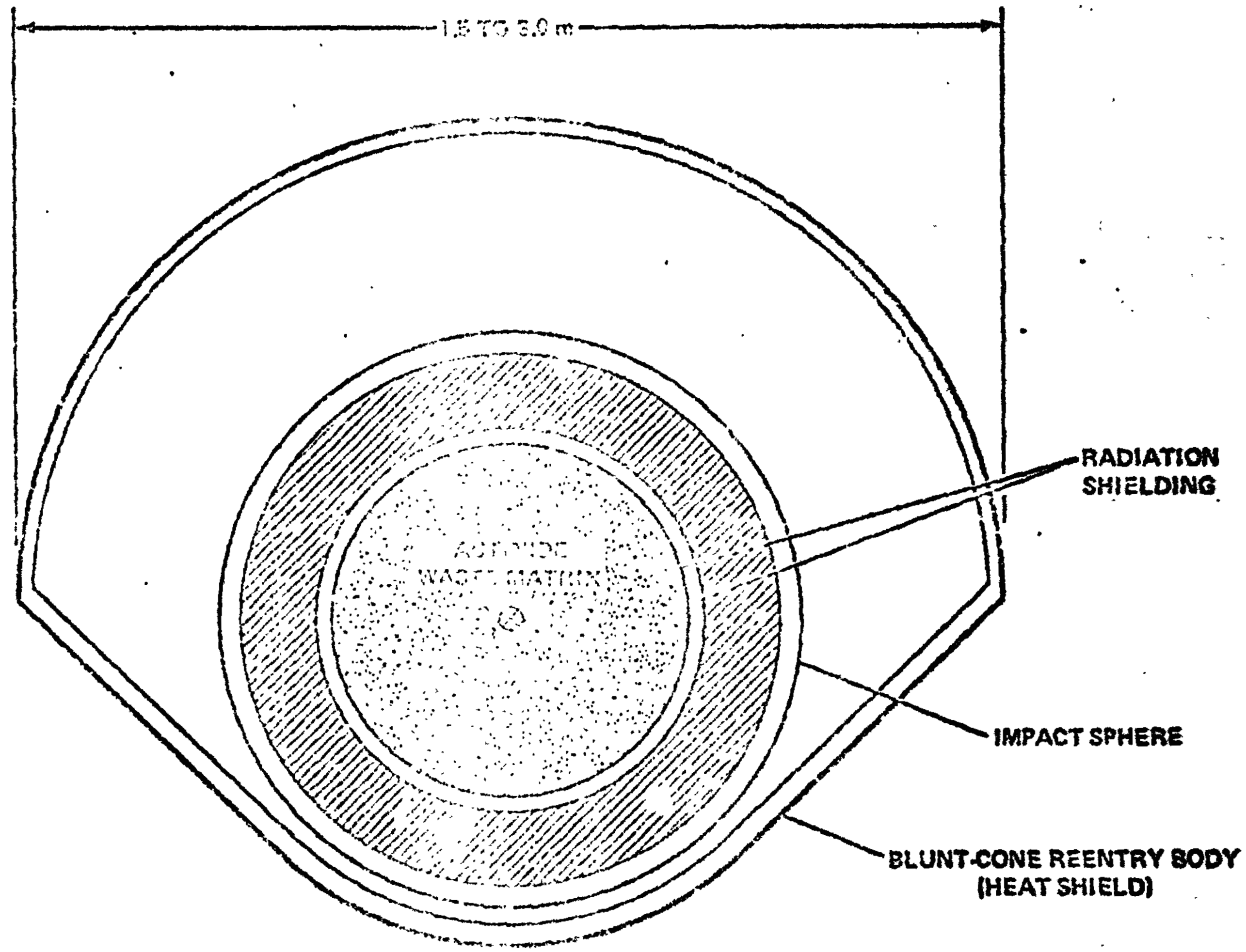
Case 3: Dispose of actinides only, with fission products separated out to within 0.1% and with 99% of the curium removed as well.

The following assumptions concerning the reprocessing and waste handling capabilities of the industry are made in analyzing the efficacy of the NASA-Hyland option for the LWR-uranium cycle.

1. Reprocessing plants pass 0.5% of the uranium and plutonium and all of the other actinides to the high-level wastes;
2. Solidified high-level wastes will be in the form of borosilicate glass with a density of 2;
3. One Mg of spent fuel reprocessed will yield 0.057 m^3 (2 ft^3) of vitrified high-level solid wastes;
4. One Mg of spent fuel reprocessed will yield about 5.7 kg of actinide oxides from calcining, assuming a fuel burn of 33,000 MWd(th)/Mg.

The total mass of high-level borosilicate glass solids produced by the reprocessing industry growth was specified in Fig. 3.5, as was associated mass of the actinides contained in it. For any reasonable amount of radiation and re-entry shielding, the total mass of the reprocessing wastes far exceeds any achievable capability for space disposal in the foreseeable future.

If the wastes are partitioned to separate out the long-lived alpha-emitting actinides, the mass problem becomes more tractable. Figure 5.5



Source: BNWL-1900

Figure 5.4

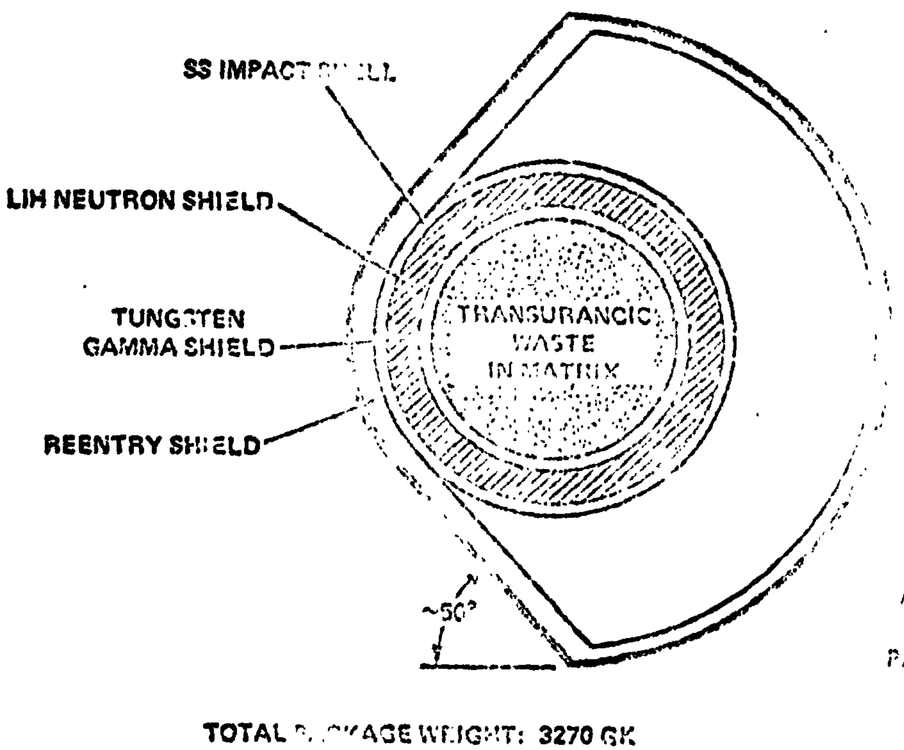
REPRESENTATIVE NUCLEAR WASTE PACKAGE

WOOD

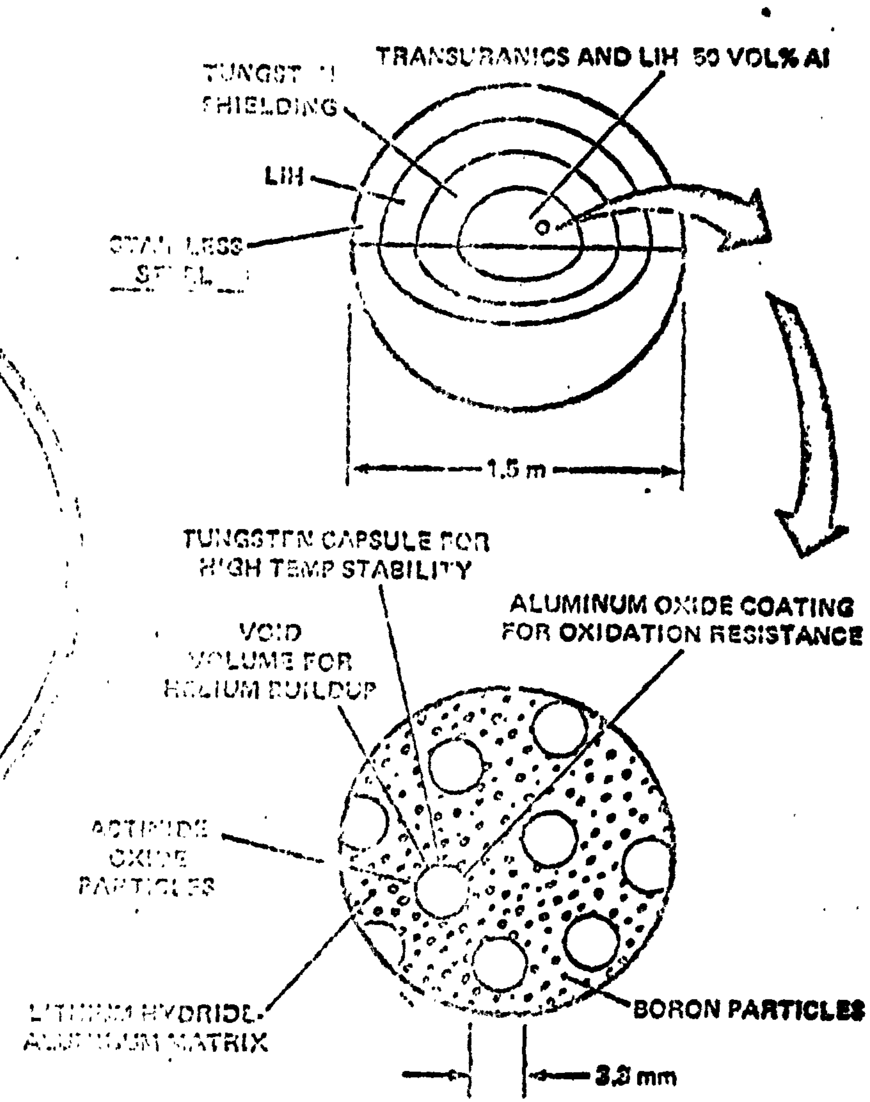
details the packaging to be given to the actinide wastes. The boron particles serve as moderators to inhibit potential criticality incidents. The LiH is present to moderate neutrons produced by (α, n) reactions between actinides and light elements such as fluorine and oxygen. The tungsten gamma shield is necessary because of the activity of the remnant fission products. The stainless steel impact shield and re-entry shield are for protection against abort and re-entry of a capsule, and the capsule itself has been shaped to ensure stable re-entry with ablation of the shield to prevent melting of the capsule.

Table 5.2 provides summary data on the contents and package configuration for Cases 2a and 2b of BNWL-1900. The payload capabilities are about 115 kg of actinides per package for 99% removal of fission products, and about 200 kg per package for 99.9% removal. Figure 5.6 plots the number of shuttle launches that would have to be performed each year to dispose of all of the actinides from reprocessing of spent fuel through the year 2000 for a nuclear industry sized according to the assumptions of Chapter 3 of this study. In generating this figure, we have smoothed out the actinide mass data of Fig. 3.5. Reprocessing capacity will increase in 500 Mg/yr chunks according to the assumptions made in Fig. 3.4, but we assume that shuttle capacity would be increased more smoothly. We also assume that waste disposal operations using the shuttle would only be tests prior to 1990, and that full-scale operation and expansion of capacity would begin in that year. By the year 2010, we assume that available shuttle capacity just matches the amount of waste produced, and that the backlog has been disposed of.

Source: BNWL-...



RE-ENTRY SHIELD AND TRANSURANIC DISPOSAL PACKAGE FOR SOLAR ESCAPE DESTINATION



TRANSURANIC WASTE CAPSULE FOR SPACE DISPOSAL

Figure 5.5

TABLE 5.2

SUMMARY DATA ON PACKAGE CONFIGURATION FOR SOLAR ESCAPE PACKAGE, FOR THE TWO PARTITIONING CASES DISCUSSED IN BNWL-1900

	CASE 2a 1% F.P. residue	Case 2b 0.1% F.P. residue
Dimensions of Package:		
Outside diameter (m)	1.81	1.81
Thickness of SS shell (cm)	0.1	0.1
O.D. of impact sphere (m)	0.98	1.04
SS impact shell thickness (cm)	2.54	2.54
LiH shield thickness (cm)	8.8	10.5
Tungsten shield thickness (cm)	4.9	3.6
Payload (kg)	3270.	3270.
Actinides per package (kg)	113.	191.
Fission products per package (kg)	40.	6.7
Re-entry shield mass per package (kg)	415.	415.
Impact vessel mass per package (kg)	567.	640.
LiH shield mass per package (kg)	135.	178.
Tungsten shield mass per package (kg)	1480.	1190.
Mass of matrix per package (kg)	505.	625.
Thermal power per package (kW)	9.26	13.25
Fission product curies	4×10^5	6×10^4
Actinide Curies	3×10^5	5×10^5

As is shown in Table 5.3, ^{244}Cm dominates both the thermal power and the radioactivity of the actinide portion of the partitioned wastes. As any reduction in shielding mass would be immensely useful in reducing the number of missions needed, it is well worth examining more closely the preconditions for their presence.

The dominant radioactive hazard from an unbroken capsule will be due to the gamma radiation from the fission product remnant, and the tungsten shield used for blocking gamma radiation accounts for a large portion of the total package mass. As shown in Table 5.2, increasing the extraction of fission products from 99% to 99.9% allows a 290 kg reduction in the tungsten shield mass. But not all of this mass reduction is available for actinides, as other characteristics of the packaging must be adjusted to compensate for increased actinide thermal power and radiation. The LiH shield for absorbing or moderating the high energy neutrons generated by (α, n) reactions would have to be increased, but as shown on the table the mass increase would be only about 40 kg. Far more significant is the necessary increase in the mass of the matrix and of the impact vessel to allow for the increase in actinide thermal power.

Because the heat generated by the wastes could cause melting or other failures of containment in the case of re-entry, the package has been designed so as to keep surface temperatures below critical values in the case of an abort. A large portion of the matrix mass consists of high thermal conductivity materials to convey the waste product decay heat efficiently to the surface of the package and keep internal temperatures at safe levels.

Figure 5.6

ANNUAL SHUTTLE LAUNCHES AND MISSIONS FOR SEVERAL SPACE OPTIONS

(Basis: two shuttle launches per mission)

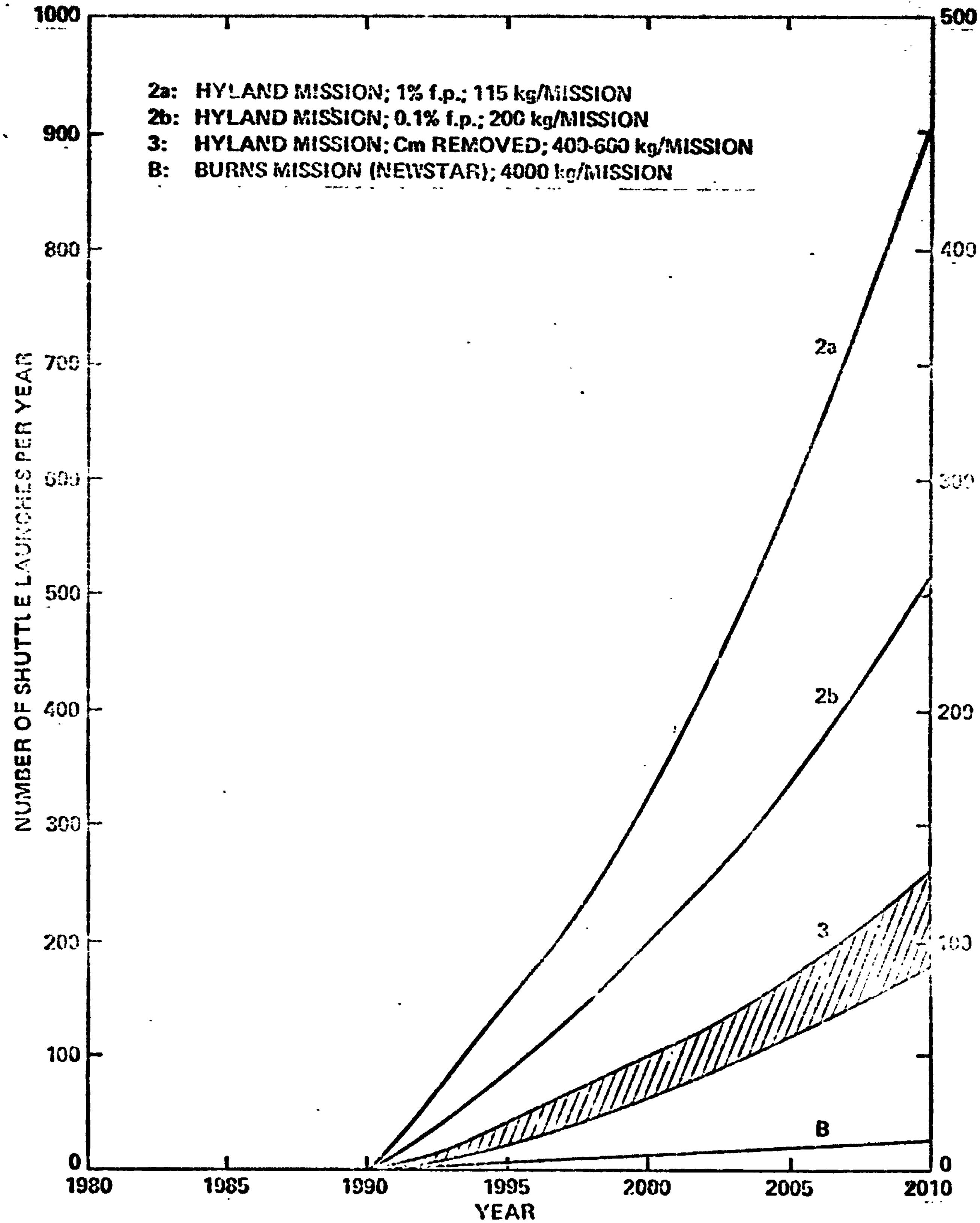


TABLE 5.3

10 YEAR WASTES, HIGH LEVEL: 99.5% Pu,U REMOVED
(Source: ORIGEN - Diablo Canyon Fuel)

Actinide Thermal Power (Watts/Mg)*

NET:	67.1	
^{244}Cm:	57.3	(85%)
^{241}Am:	5.4	(8%)
^{238}Pu:	3.1	(4%)
Subtotal	65.8	(97%)

Actinide Radioactivity (Ci/Mg)*

NET:	2,300	
^{244}Cm	[illegible]	[illegible]
^{241}Am	160	(7%)
^{241}Pu	320	(14%)
Subtotal	2,120	(92%)

*Referred back to net spent fuel mass

The removal of the curium from the wastes thus appears to be a desirable goal as an adjunct to space disposal. Curium reduction could also be effected by managing the fuel cycle somewhat differently, and we shall discuss this possibility later in this section. A detailed analysis of Case 3, curium removal, was not performed in BNWL-1900, as there were no available technologies for doing so. It was estimated that large increases in payload could result. The LiH shielding could be greatly reduced, or removed completely. This would also make the package size slightly smaller, reducing the mass of the impact sphere. The amount of Cu or Al placed in the matrix for heat removal could be much reduced. As shown in Table 5.4, this is a considerable fraction of the total mass. The package size is also determined by the heat conductivity from spherical heat sources to the surface [illegible] low. Removal of the primary heat source could allow a redesign for greater efficiency of packing. When all these factors are taken into account, it is estimated that the actinide mass per waste disposal package could be doubled, reducing the number of missions by a factor of two. This estimate could be on the conservative side. This case is also displayed on Fig. 5.6.

<u>The NASA-Burns Study.</u>

A second study on the disposal of nuclear wastes in space was recently performed by a team from the NASA Marshall Space Flight Center under the direction of R. E. Burns.[2] Again, we shall refer to this as the NASA-Burns study for convenience without meaning to play down the roles played by other contributors on the study team.

TABLE 5.4

COMPOSITION OF TRANSURANIC WASTE IN SPACE DISPOSAL CAPSULE

Material	kg/liter	Total kg in Single Sphere
Li-6	0.1120	6.325
Li-7	0.1610	9.092
Cu	1.9900	112.376
O	0.1080	6.099
Al	0.6050	34.164
H	0.0420	2.360
Np-237	0.6180	34.898
Pu-238	0.0049	0.276
Pu-239	0.0223	1.257
Pu-240	0.0163	0.920
Pu-241	0.0024	0.135
Pu-242	0.0016	0.088
Am-241	0.0458	2.589
Am-243	0.0746	4.213
Cm-244	0.0175	1.005

Note: Sphere volume = 56.46 liters.

MATERIALS AND DIMENSIONS OF SPACE DISPOSAL CAPSULE

Shell	Material	Density g/cm^3	Radius cm	Thickness cm
--	Transuranics + Matrix	--	23.8	--
1	Tungsten	19.3	27.02	3.22
2	LiH	0.82	34.62	7.60
3	Stainless Steel	7.93	37.16	2.54
4	Carbon	2.1	38.16	1.00

Unlike the NASA-Hyland study, the wastes are not treated here as passive payloads to be maneuvered into escape orbits. In the proposed vehicle, known as NEWSTAR, the actinide decay heat is used to drive an electric ion propulsion system. This is said to be more efficient than the chemical thrusters suggested for the NASA-Hyland tugs. The proposed vehicle, which uses mercury ions for propulsion, is shown in Figs. 5.7 and 5.8. The actinides are to be packaged in an array of circular canisters surrounded by radiation shields. The heat from the wastes is conveyed by heat pipes to a set of thermionic diodes. The electricity generated is converted to high voltage by power conditioning units and used to drive the mercury ion thrusters.

As with the NASA-Hyland proposal, the space shuttle will be used to stage the vehicle to earth orbit, [illegible] mission. A typical mission profile would be as follows:

1. Launch shuttle #1 to parking orbit.
2. Deploy expendable chemical space tug to rendezvous.
3. Launch shuttle #2 to orbit.
4. Deploy NEWSTAR and attached waste package to rendezvous.
5. Dock NEWSTAR to chemical tug and remove shields.
6. Shuttle #2 recovers shields and returns to Earth.
7. Chemical tug powers payload to Earth escape.
8. NEWSTAR ion propulsion powers payload to direct solar escape.

Figure 5.9 shows the NEWSTAR package in the shuttle payload bay. The actinide payload permission is estimated to be about 4 Mg, as listed on Table 5.5.

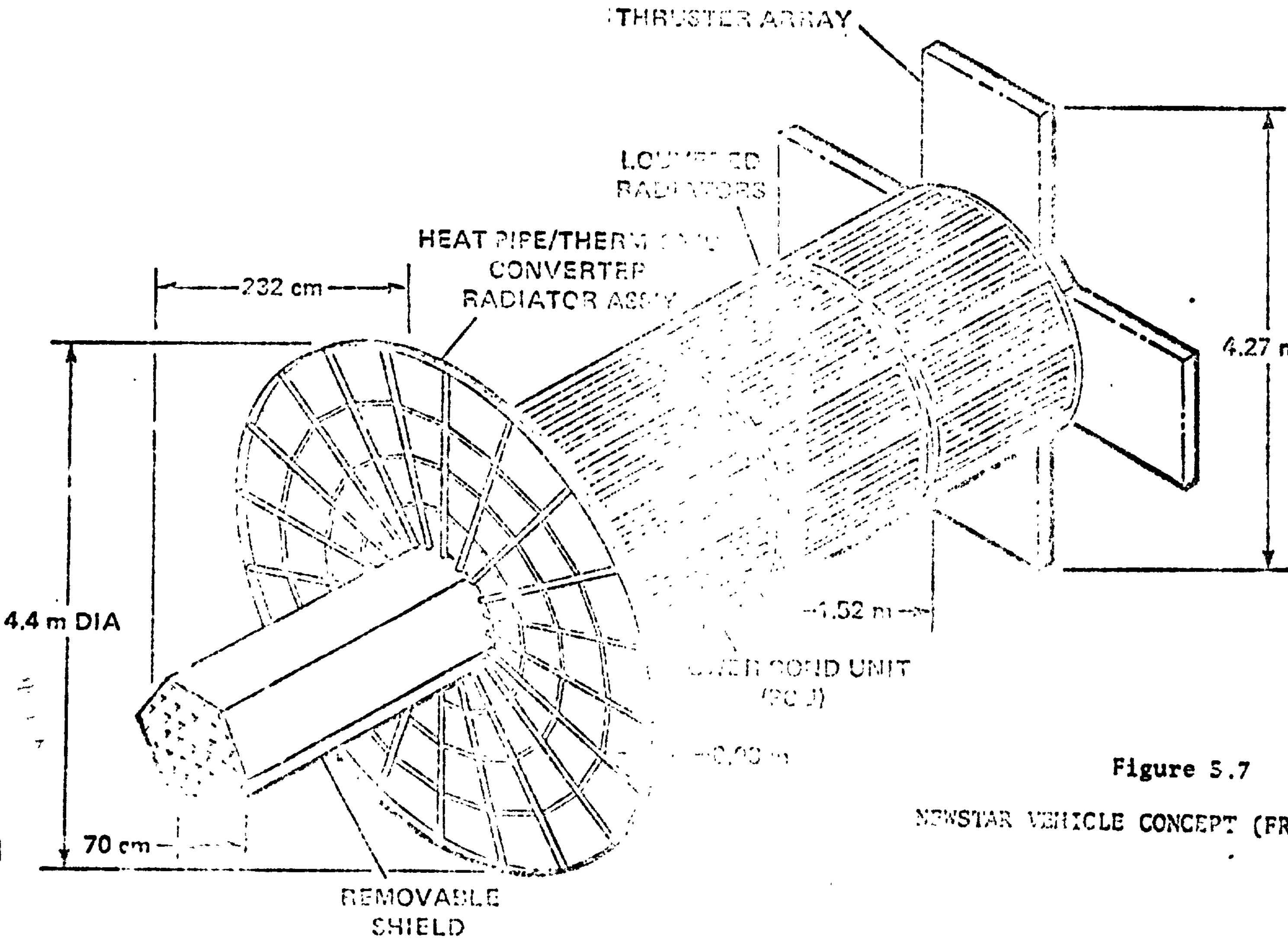


Figure 5.7

NEWSTAR VEHICLE CONCEPT (FRONT VIEW)

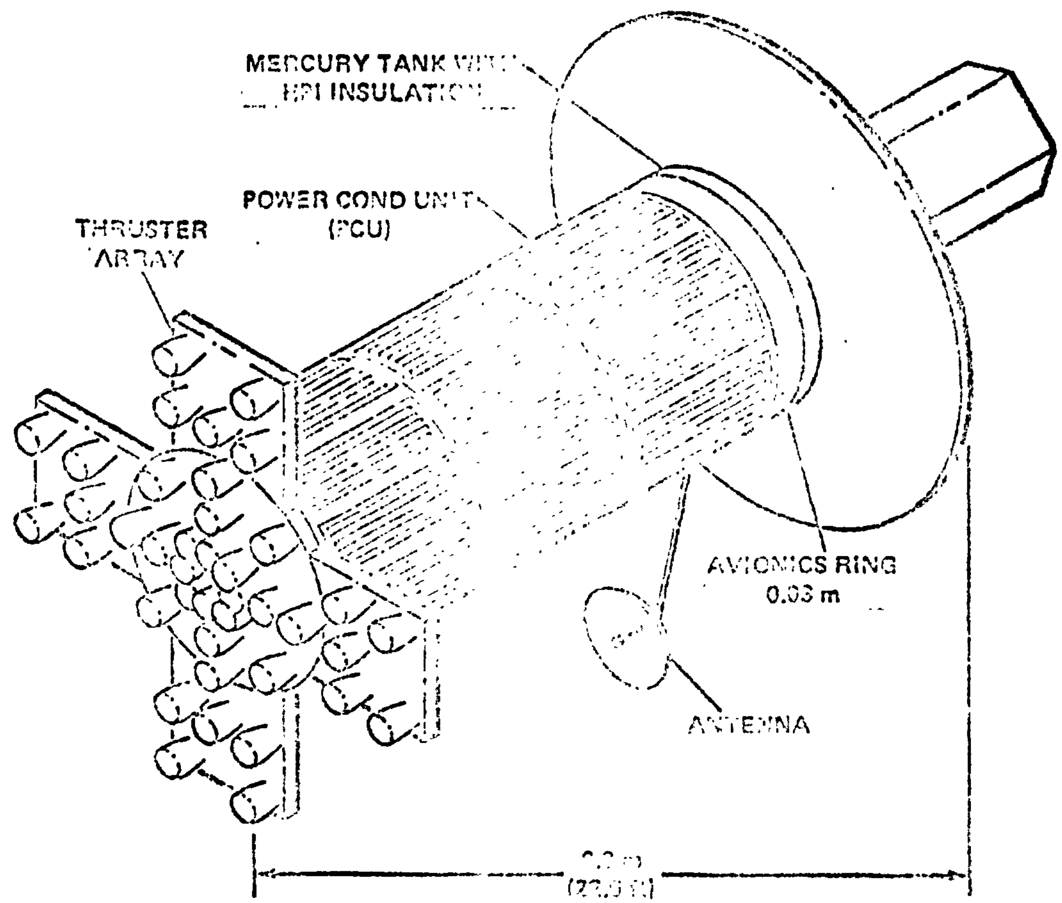


Figure 5.8

NEWSTAR VEHICLE CONCEPT ([illegible])

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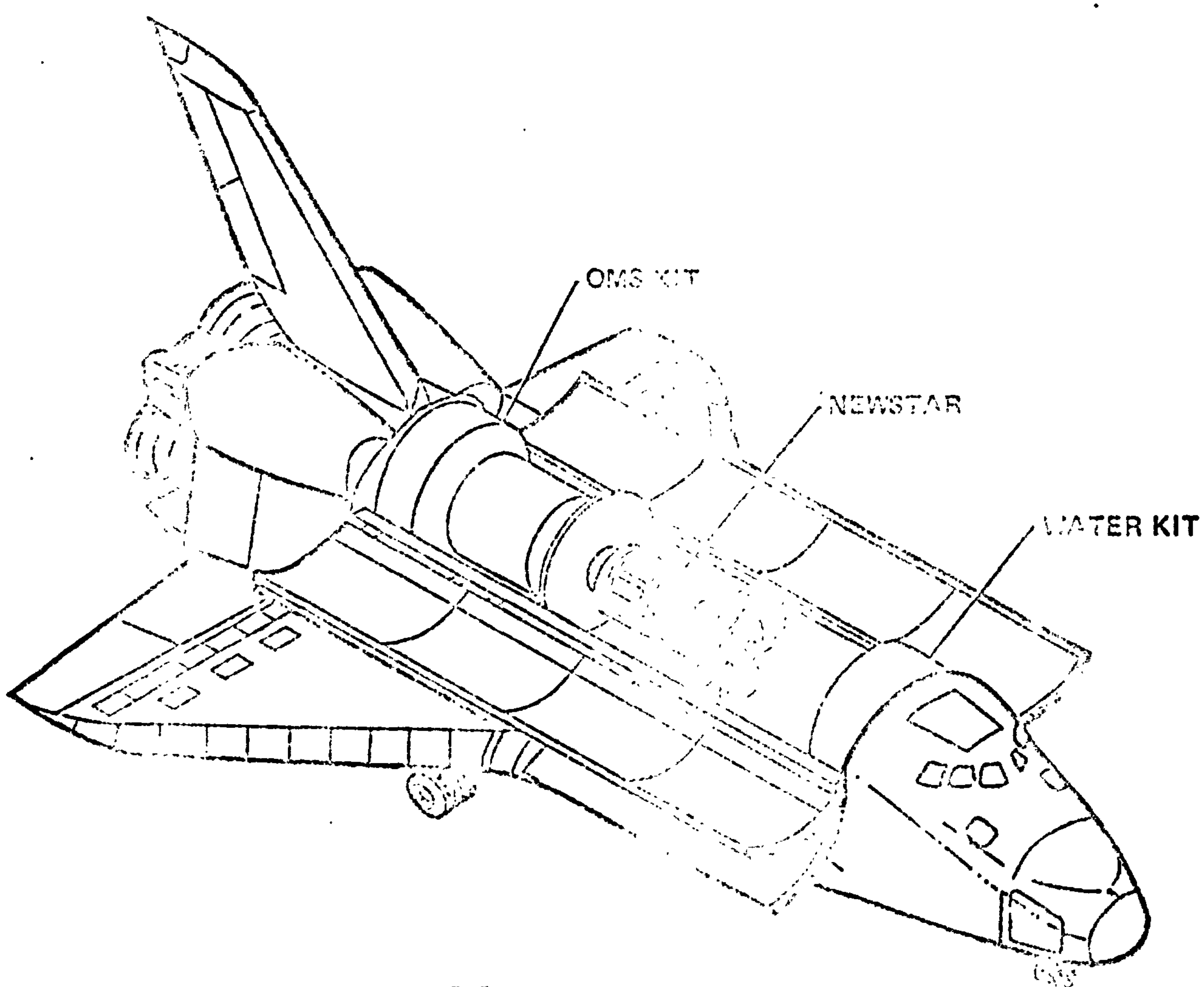

Figure 5.9

NEWSTAR IN SHUTTLE PAYLOAD BAY

However, it is not possible to directly compare the number of required NEWSTAR launches with the previous results of the NASA-Hyland Study. Under the assumptions made in the NASA-Burns report, a rather large power density of 0.1 kw/kg is required for powering the thermionic diodes. As shown in Table 5.6, this power density is not available at present. 99.5% recovery efficiency for uranium and plutonium, and better reprocessing efficiency would be required.

The use of retrievable shields as suggested for the NEWSTAR vehicle could also be used for an all-chemical tug, and would markedly increase the payload of the vehicle. However, the NEWSTAR design, unlike the NASA-Hyland package, is not capable of an unassisted ballistic re-entry or subsequent burial in soft soil of low thermal conductivity. Furthermore, the required improvements in reprocessing efficiency are unlikely to come about within the next few decades. For these reasons, the NEWSTAR idea must be treated as an interesting, but still quite hypothetical, method for space disposal.

The Role Played by ^{244}Cm

In both the Hyland and the Burns studies, curium plays a central role. The primary source of both alpha radiation and heat in partitioned high-level wastes is ^{244}Cm. In the Burns study, this heat is necessary for driving the propulsion system. In the Hyland study, it is responsible not only for a great deal of the mass of the encapsulation package, but is also the major determining factor in the entire package design. The containment sphere is sized so as to produce a favorable ratio of package surface to volume to ensure that the heat generated can be effectively dissipated. Yet, there is no documentation presently available that indicates that the levels of ^{244}Cm

TABLE 5.5

NEWSTAR WEIGHT SUMMARY (kg)

Subsystems scaled for NEWSTAR		822
. Propulsion	253.8	
. Communications	55.4	
. Command computer/data handling	32.6	
. Guidance and navigation	32.3	
. Power storage and distribution	270.0	
. Reaction control	23.8	
. Propellant system	154.3	
NEWSTAR unique systems		3,653
. PC modules	861	
. Thermionic converters	179	
. High temperature radiator	392	
. Actinide packaging (includes heat pipes)	793	
. Structure	450	
. Thermal insulation	458	
. Miscellaneous	63	
15 percent contingency	477	
Propellant (includes 1 percent FPR)		6,[illegible]
Actinide Waste		4,140
NEWSTAR initial weight		14,900
Removal shield		4,772
. Polyethylene	789	
. Attitude control kit	25	
. Tantalum	3,958	
Ascent Cooling		3,100
. Water	2,100	
. Tank, lines, etc.	1,000	
Cocoon		2,275
Attachments		1,500
Shuttle contingency		2,677
TOTAL		29,224[a]

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[a] Shuttle capability for launch from Cape Kennedy AZ = 108°.

TABLE 5.6

ACTINIDE THERMAL POWER FOR WASTES FROM [illegible]-DAY REPROCESSING OF SPENT FUEL, WATTS/GRAM

(Basis: 30MW(th)/Mg, 33,000 MWd(th)/Mg burn, fission products excluded)

YEARS FROM REPROCESSING	LWR-U 99.5% REMOVAL OF U,PU	LWR-U 99.[illegible] REMOVAL OF U,PU	LWR-U 99.9% REMOVAL OF U,PU	PU RECYCLE* 99.9% REMOVAL OF U,PU
0	0.13	[illegible]	1.08	0.98
5	0.014	[illegible]	0.122	0.24
10	0.012	[illegible]	0.10	0.20

*Average waste mix, 11% MOX fuel, 89% enriched uranium fuel.

projected for future high-level wastes will be reached. Present wastes are almost certain to contain far smaller proportions than were calculated on the basis of 33,000 MWd(th)Mg in Chapter 3.

The difficulty with the projections is that almost all waste management documents put forth by the AEC and ERDA have based their figures on the ORIGEN runs for model Diablo Canyon reference fuel burned to 33,000 MWd(th)/Mg.[5] For the LWR-U fuel cycle, the production of 244Cm is a high-order process,[6] as six separate neutron captures must occur for ^{238}U to be converted ultimately to ^{244}Cm. The production rate of curium is thus very sensitive both to fuel burn and to total burn up times. If the neutron flux is smaller than specified, or if the fuel is not given a full 1100-day burn, the quantities of ^{244}Cm produced will be considerably smaller than those we have been using.

Figure 5.10 plots the production and decay for a number of the actinides according to the output of the ORIGEN code. The assumptions are: a geometry and fuel management schedule (placement in the core, etc.) similar to that planned for the Diablo Canyon reactor; a neutron flux of 2.92×10^{13} neutrons/cm^2-sec; 3.3% enriched uranium fuel; a power density of 30 MW(th)/Mg of heavy metal. Actinide quantities are plotted as a function of operating time up to a full burn of 1100 days, corresponding to a burnup of 33,000 MWd(th)/Mg. Because the production of curium is a high-order process, it accumulates very slowly at first, building up only at the end of the burn.

As the rate of production of ^{244}Cm is rising very rapidly at the end of the burn period, the actual quantities of this isotope present in the high-level wastes will be very sensitive to operating practice. We do not have the resources in this study to examine the effect of reducing the reactor power below the stated rating, of changes in core geometry,

C-3

or of design. These would markedly affect the curium production, as well as that of other transuranics. We therefore restrict ourselves to considering only the effects of operating practices and fuel management insofar as they affect the residence time of the fuel in the core, stipulating full power uninterrupted operation.

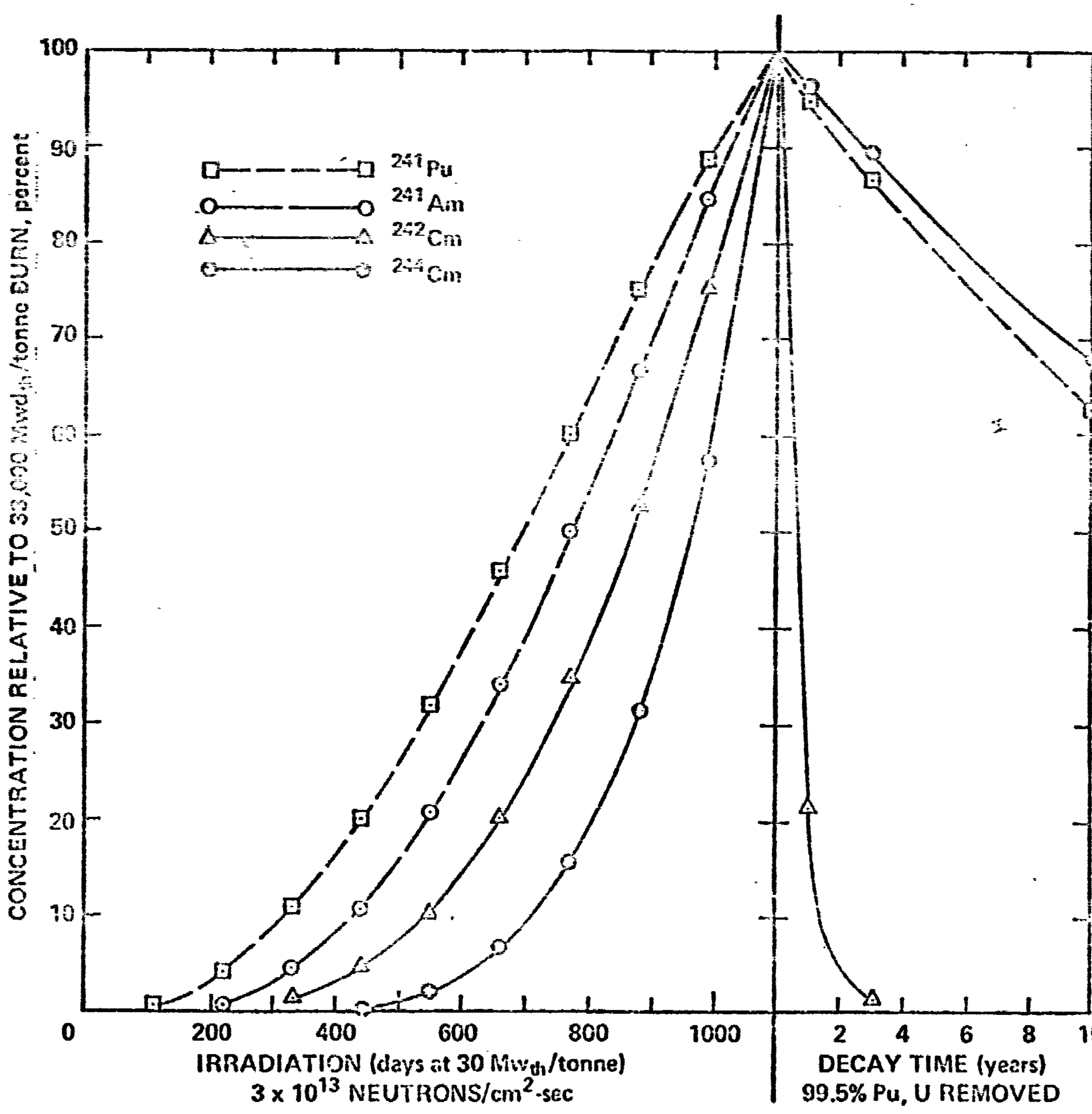
It is clear from Fig. 5.10 that a factor of three reduction in the amount of ^{244}Cm produced can be obtained merely by removing the fuel at 80% of its stipulated rating. This would still give a very good burnup of 26,400 MWd(th)/Mg. It has in fact been suggested to us that ratings in the vicinity of 25,000 MWd(th)/Mg would be more realistic over the next few decades than current ERDA figures. It is certainly doubtful that any of the spent fuel presently in storage or to be available in the near future will even come close to this figure. Given present fuel burns, capacity factors, and refueling procedures, we expect that little of the spent fuel will have been burned to even 20,000 MWd(th)/Mg.

Thus, even if the ORIGEN code is a good predictor of the rate of isotope production in current reactors, we believe that there is very little ^{244}Cm in present spent fuel. Actual fractional inventories ^{244}Cm may be as low as 5-10% of the ratios used in the Hyland or Burns studies. If this is the case, the analyses presented in the two NASA studies to date must be altered to take into account this very significant difference in the properties of the high-level wastes. The continued assumption that the burnup figure of 33,000 MWd(th)/Mg is correct is more than "just" a serious error in computing waste characteristics. For if the spent fuel does and will have an appreciably lower ^{244}Cm content than has been specified, the NEWSTAR vehicle proposed in the Burns study will never be

Figure 5.10

ORIGEN - DIABLO CANYON LWR-U ISOTOPE PRODUCTION:

30 Mw_{th}/tonne



Source: ORIGEN - Diablo Canyon LWR-U

able to operate, and the cost figures and numbers of missions required quoted in the NASA-Hyland study are at least a factor of two too high. If this is so, then the projections for missions made in Case 3, as shown in Fig. 5.6, are actually appropriate as an upper bound for Case 2b instead, without the necessity for the development and installation of curium extraction procedures.

Even if we do suppose that the ^{244}Cm production is at or above the level specified by the full burn of 33,000 MWd(th)/Mg, the existence of the NEWSTAR idea might make Case 3 more tractable than was assumed in the BNWL-1900 study. The decay of curium produces plutonium, and it would make no sense to dispose of the other transuranics in space and leave the curium behind. In an extension of the arguments made in Chapter 4, space disposal of all the actinides except the curium would not be sensible if curium production were as high as is stated. On the other hand, we have shown that projected LWR-U wastes will not have enough thermal power to run NEWSTAR given reasonable assumptions about the efficiency of reprocessing. If the curium were separated, the separated fraction would be a marvelous source for powering a NEWSTAR. Owing to the very high thermal power of this fraction, it would be possible to fit the waste package with a full set of ballistic re-entry shields and thermally sink it so that even burial in soft soil would not cause difficulties. Looking at the mass ratios quoted for the transuranics, curium accounts for less than 1% (assuming 99.5% efficiency in removal of uranium and plutonium during reprocessing). This would require very few NEWSTAR shots. An interesting proposal might then be to dispose of the rest of the actinides via passive packages according to the method described in the NASA-Hyland study, but with a very much increased actinide payload owing to the removal of curium. This could be instituted as a fairly routine procedure. The far more expensive and possibly more hazardous NEWSTAR launches would be very infrequent--about one for every one hundred conventional launches--and far more elaborate safety checks, monitoring, and control could be instituted. The conventional package launches would take place at the frequency specified by our estimates of Case 3 on Fig. 5.6, the NEWSTAR missions rising to only about one per year by 2010.

Space Disposal in the Context of
Complete Fuel Cycle Management.

From the preceding discussion and the issues raised in it is clear that space disposal is not an add-on accessory to the nuclear fuel cycle. It will never develop and be implemented if the other parts of the cycle are independently optimized and managed, for that will result in decisions that would totally preclude space operations at any reasonably achievable level even if they were held to be the most desirable method for the disposal of the wastes.

For instance, let us consider the curium problem once more. The pursuit of the full rated fuel burnup of 33,000 MWd(th)/Mg is never questioned as a desirable goal in literature relating to reactor operation or to the fuel cycle in general. Higher burns would use the fuel more efficiently and produce smaller total quantities of waste per unit of electricity generated. From both the technical and resource standpoint, then, ever-increasing fuel burns would appear to be highly desirable. However, the overall reduction in ore requirements and mass and volume of spent fuel is achieved at the expense of quantitatively greater production of the higher actinides such as americium, curium, californium, etc. This would have major effects on the operation of any waste management strategy that requires the partitioning of the actinides. Although plutonium is the nuclide that produces the most concern over the long term, it is the transplutonic elements that present the most problems for operation of the disposal system.

However, as we have pointed out, the "back-end" of the fuel cycle--reprocessing, recycle, and most especially waste management--have not received due consideration in operational planning or reactor design and operation. If great concern for operational efficiency, operator convenience, and maximum use of available enrichment capacity are allowed to dominate fuel cycle planning, the trend to ever higher fuel burns will undoubtably continue, further exacerbating the difficulties of dealing with high-level wastes.

Even the advent of reprocessing and the associated attention being paid to it and to Pu recycle will not change this. The reprocessors are interested primarily in the least costly method of meeting the forthcoming regulatory requirements for waste management. They will most probably choose some form of vitrification for the high-level wastes and thus prevent any possibility of partitioning, at least for the wastes to be produced in the foreseeable future.

There would appear to be little leverage that could be exerted upon these conditions even by a demonstrably operable space disposal system. What would be required would be a social and political decision that space disposal was the most desirable and efficacious method of eliminating the long-term problem of high-level nuclear wastes, and a determination to manage the rest of the fuel cycle to facilitate this. That such a decision would be made is not entirely impossible, albeit unlikely. But it is not probable in the immediate future. Nevertheless, it would be remiss not to go through the exercise of examining the impacts of a possible space disposal program so that those making the decision will at least be informed as to whether it should be considered at all.

Can Space Disposal Deal with the No-Growth Case?

In Chapter 3, we raised the question of Case F, a commitment to bring nuclear power to a complete halt as soon as practicable, and the possibility that space disposal would be one of the methods sought out for removing the wastes produced permanently from the biosphere. The question then is to what extent space disposal might be usable in this case.

The spent fuel even for Case F will amount to about 2500Mg/yr. As the specific power of the spent fuel will not be adequate for the NEWSTAR type of vehicle, we must assume passive disposal would be used. The high activity of spent fuel, however, would not allow payloads to be much increased over those shown on Table 5.2. The enormous number of missions involved would not allow disposal of undifferentiated, unprocessed spent fuel even in this minimal growth case.

As in Chapter 3, we may then assume that the spent fuel is reprocessed primarily to facilitate waste disposal, but that only the U is extracted for recycle and further use. All of the Pu is then allowed to follow the other actinides into the high-level wastes. This is not altogether unreasonable, as it is the separation of Pu from the other components that raises the greatest concern over theft or diversion of materials. As the net mass of

Pu is still small compared to the other products in the waste, and as the Pu contributes little of the activity or thermal power, the packaging and operational conditions would be nearly the same as for the cases previously discussed.

The major difference, then, would be in the scope of the operation. For the industry size predicated by Case F, as shown on Fig. 3.4, less than 3000 Mg of reprocessing capacity would be necessary. The total amount of high-level wastes produced, allowing for the increase in Pu, would come to about 200-250 Mg/yr, which would still require between 500 and 1000 missions (depending on the packaging), or 1000-2000 shuttle launches annually to dispose of the total high-level wastes.

Therefore, unless such a commitment is made out of determination to eliminate the problem for once and for all at any cost, it would still be necessary to go to partitioning to reduce the number of shots. Assuming a reprocessing efficiency of 99.5% for U, the asymptotic operational levels would be:

80 missions/yr (160 launches) for Case 2a packaging; (1% fission products)

50 missions/yr (100 launches) for Case 2b packaging; (0.1% fission product

20 missions/yr (40 launches) for Case 2b if there is little or no curium.

Peak levels would be reached around the year 2000 to reduce backlogs of spent fuel, and would be at levels 50% above those listed.

The Impact of Plutonium Recycle

Although we have held ourselves to examining only an LWR-U economy, the discussion of the curium problem requires that the impact of going to plutonium fuel be considered. This is one example of a policy decision that would have a profound impact on a potential space disposal program. The difference between the equilibrium waste output of a reactor economy using only uranium and that with the GESMO plutonium recycle conditions has already been noted.

In the GESMO and related documents it is usually stated that, although the wastes from the burning of MOX fuel will have considerably higher heat output and alpha activity than those from uranium fuel, mixing them back in with the other wastes will result in only a small upward adjustment in the thermal power and radioactivity of the overall high-level wastes. But even with the mixing, the overall amount of americum, curium, and plutonium in the wastes will be much higher than for an all uranium cycle. This is particularly true for curium. The uranium cycle starts with no isotope having a higher mass than ^{235}U. The production of ^{244}Cm is then a sixth-order neutron capture process. In the equilibrium MOX cycle, recycle fuel will contain an appreciable fraction of ^{240}Pu and some ^{241}Pu as well. Thus, production of ^{244}Cm is roughly a fourth-order process,[6] and the MOX spent fuel will contain about 50 times as much ^{244}Cm as uranium fuel.

In terms of waste management policy, Pu recycle may be discussed thus. The nature of the space option is such that a choice to go to space is unlikely to be made independent of other choices about the fuel cycle. If the method discussed in the Hyland study is the usable option, then every consideration will have to be given to reducing the amount of ^{244}Cm in the wastes, either by reducing the power density of the total burnup of the fuel. However, reprocessing is a necessary precondition for even generating the high-level wastes, and this results in the separation of plutonium. Should this lead to a decision to recycle the plutonium in order to decrease the amount of enrichment capacity needed or because of real or feared shortages of uranium ores, then this decision would preempt any further attempts to manipulate the fuel cycle on behalf of space disposal. As shown in Table 3.10, the relatively small amount of MOX fuel would completely swamp any effects that management of enriched uranium fuel would have on the production of curium.

If NEWSTAR were to prove practicable, the situation would, of course, be different. The large amounts of curium present would not only be desirable, but necessary to obtain partitioned actinide wastes with high enough thermal power densities to run the thermal-ion propulsion system without also having to increase the efficiency of reprocessing plants by an order of magnitude or more.

Why We Choose 10, 100, and 1000 Shots/Year to Study

Past studies[1, 2, 3] have attempted to accurately predict both the size and character of the nuclear industry, the development and installation of commercially feasible technologies, and the rate of potential development of such processes as partitioning in order to project the scope of a hypothetical space disposal program. We have a more modest view of our predictive abilities. As we are not attempting to estimate operational costs, but social, resource, and policy requirements and impacts of a potential space disposal program, it is also of less significance for the purposes of this study that predictions be precise. What we do need to estimate is the rough scope of the program. Yet, our predictive abilities do not suffice even to guess within a factor of two or three. As a result, we have chosen three differently sized programs to examine: one very small, one very large, and one about the size of that predicted by the Hyland study as corrected by our own projections of the size of the nuclear industry.

10 launches annually by the year 2000

The smallest program we have chosen to consider represents only a fraction of the planned available shuttle launch capability by the year 2000. As such, we expect that it would not have a major impact on manufacturing or operational capacities, or strain NASA's reserves in any way.

This case could arise from a number of circumstances. The advent of NEWSTAR or some similar program that makes the actinide payload an appreciable fraction of the lift capacity of the shuttle would hold the requirements down to this number of launches. Or, as has been suggested elsewhere, space disposal might be considered too expensive or risky for a full-scale disposal program, but would be used to get rid of a few particularly troublesome and long-lived isotopes such as ^{129}I. In the latter case, the small number of annual launches required would instill confidence in the ability to closely check and monitor the disposal flights, and even to provide a back-up system to deal with potential aborts. Cost would not be a major factor for this type of mission.

100 launches annually by the year 2000

This program, intermediate in size for this study, is somewhat smaller than that predicted by BNWL-1900 for implementation of a system similar to that proposed in the NASA-Hyland study. It would, however, be correctly sized for the nuclear industry projections made in this report if the fuel cycle were managed in such a way as to minimize the production of ^{244}Cm, as the payload per shot would be increased by a factor of two or three over that used for the BNWL-1900 projections.

Clearly, this size program would no longer be a sub-operation of the projected shuttle program, but would require considerable expansion of manufacturing, operational, and launch capabilities.

<u>1000 launches annually by the year 2000</u>

The only way to describe this is an enormous program, one that would strain not only NASA's, but the nation's resources as well. However, this is the size of operation that would be required if the decision were taken to recycle plutonium and still use space disposal to remove the long-lived alpha-emitting actinides permanently from the planet. It is also closer in size to our estimates of the scope of an unmodified program such as that suggested in the Hyland study if the fuel cycle were not managed to keep curium production low.

For this case, many launch sites would be required in addition to Cape Kennedy, and a whole new operational system would have to be devised just to manage orbital traffic. It is most probable that this would be beyond the scope of NASA to manage, and either an industry or a new agency would have to take over responsibility for the program.

NOTES TO CHAPTER 5

1. R. E. Hyland et. al., Feasibility of Space Disposal of Radioactive Nuclear Waste, NASA Technical Memorandum TM X-2911 (Executive Summary), NASA Lewis Research Center, December 1973.
2. R. E. Burns et al., Nuclear Energy Waste-Space Transportation and Removal, NASA Technical Memorandum TM X-64915, NASA Marshall Space Flight Center, December 1975.
3. High-Level Radioactive Waste Management Alternatives, Report #BNWL-1900, Battelle Pacific Northwest Laboratories, Richland Washington, May 1974. A summary version of this document was released by the AEC as WASH-1297.
4. Present practice is to hold to an annual refueling schedule [illegible] of the fuel burn. As capacity factors are currently between 50% and 60% for most reactors, present spent fuel inventories have a rather low average burn, probably below 20,000 MWd(th)/Mg.
5. M. J. Bell, ORIGEN - The Oak Ridge Isotope Generation and Depletion Code, report #ORNL-4628, Oak Ridge National Laboratory, May 1973.
6. See Figure 3.9 for an explanation of this point.

Ibid.

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CHAPTER 6

WHAT IS NEEDED TO MAKE THE PROGRAM A REALITY:

RESOURCE, MANAGEMENT, AND INSTITUTIONAL REQUIREMENTS

Introduction

Certain [illegible], certain "inputs," would be required in order to establish an actual space disposal program. In particular, NASA and its contractors would need these inputs:

--The necessary technological sophistication.

--The necessary resources, including materials such as appropriate materials to build the shuttles, fuel to fly them, construction facilities to manufacture the equipment, skilled personnel, and adequate capital.

--Proper management (1) to overcome any resource logistics problems and thus to ensure that the program has the resources it needs, (2) to use these resources to build the program, and (3) to run program operations.

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--The necessary institutional arrangements, in effect, legal and practical "permission" to acquire resources and then go ahead with the program. Note that in the case of space disposal, "permission" to establish the program is needed from foreign governments, as well as from U.S. agencies and such non-government institutions as labor unions and aerospace corporations.

Chapter 4 and 5 have already discussed the technology needed for space disposal. This chapter discusses the basic resources, management features, and institutional arrangements needed to establish a shuttle-based space disposal program.

Even though data, especially quantitative data on the resources needed, were scanty, a preliminary discussion of these matters provides useful information. Of particular importance is an attempt to identify "bottlenecks" that might arise, especially, the logistics problems that would affect the overall feasibility of developing a given sized program within a given amount of time. We also discuss some of the management strategies and institutional arrangements that might be needed to cope with such bottlenecks.

Such an analysis also enables one to identify the important policy questions that NASA decision-makers will face if they wish to establish a full-scale space disposal program--policy questions regarding resource acquisition, especially financing; special management issues, such as the advisability of new personnel training programs; and the content of institutional arrangements on such features as liability, relations between NASA and other agencies, and between NASA and other countries.

As a preface to our discussion we shall reiterate two obvious points. First, waste management programs, like all human activiites, involve both technical hardware and human organization. Shortcomings in either will affect how well a program is established and operated. Thus in analyzing proposals for the disposing of radio active waste in extra-terrestrial space at least as much attention should be paid to management and institutional considerations as to technical ones.

Second, any waste management program will become quite large as the program "goes to scale", i.e. changes from a program which is a small, essentially R&D-oriented unit, to a large, full-scale operational program; its character changes profoundly. The two types of projects are very different, not only in quantitative terms of size, cost, and so forth but also in qualitative terms. They require quite different managerial and institutional approaches.

As a project "goes to scale" at least two types of changes occur, and special management and institutional problems are associated with each. As the project grows and expands--the quantitative aspect of going to scale--problems are generally ones of logistics. Resource "bottlenecks" can threaten to limit or slow down the growth of the project. As growth continues, the project also "goes to routine," i.e., these processes which were once informally carried out became standardized, documented and routinized. This results in part from increasing demands on the program: that it move away from an R&D orientation, to one emphasizing smooth, efficient performance on a large scale. At the same time, the "personality" of the program also changes. It goes from a small, exciting project full of highly qualified, highly motivated people to one of more routine, ev . boring operations, where diligence and competence may decline.

Resources Required to Make a Shuttle-Based Space Disposal Program a a Reality: at Varied Levels of Required Numbers of Launches.

Since one cannot predict just how large an actual space disposal program might become, we have decided to use three "scenarios," introduced in Chapter 5, to illustrate what forms a shuttle-based program for sending the wastes out of the solar system might take. The scenarios differ primarily in the number of launches required each year by the year 2000: 10, 100, and 1,000 launches per year. This chapter attempts rough, preliminary estimates of what resources each of the three launch levels would require. It is clear that those areas where our numbers are most skimpy would be prime subjects for further research on the space disposal idea.

Total payload assumptions. Based on the discussion of Chapter 5 above and on the BNWL-1900 report the following summary figures were used as a base line for the analysis in this chapter. If 99.0% of the fission products in the radioactive wastes are removed, leaving only 1% fission products in the transuranics, then about 115 kg. of transuranics would be disposed of per space "mission": however, each "mission" requires two shuttle launches for its completion--one to lift the payload and the other other to lift the special "upper stage" rocket needed to send the payload on its journey out of the solar system. If 99.9% of the fission products were removed, then about 200 kg. of transuranics would be disposed in each two launch mission. Thus the various "launch level scenarios" would dispose of the following amounts of waste per year:

	Number of Launches per Year		
	10	100	1000
99.0% FP out	575 kg	5,750 kg	57,500 kg
99.9% FP out	1,000 kg	10,000 kg	100,000 kg

Shuttle equipment needed. NASA estimates that a given shuttle orbiter could be re-launched every two weeks (or 25 flights per year).[1] At this rate of re-use, the various space disposal scenarios would require the following numbers of orbiters for regular use with additional orbiters to back-up machines.

--10 LPY (launches per year): 0.4 of one orbiter's time.

--100 LPY: 4 orbitters required full-time

--1000 LPY: 40 orbiters required full-time

NASA anticipates that an orbiter will be able to fly 100 times before needing a major overhaul (4 years of operation, if it makes 25 flights a year. With an overhaul every 100 flights, the agency estimates that an orbiter can last 500 flights altogether.[2] Thus the waste disposal life time of an orbital design exclusively to this mission would be for the three scenarios, 50, 20 and 20 years, respectively.

Other shuttle equipment would have to be replaced more often that orbiters. The solid fuel boosters (two needed for each flight) can be recoved and refurbished; but after being used some 20 times, they have to be discarded. And the external fuel tanks last only one flight.

The "upper stages" (space tugs) used to end the waste packages into deep space can be either reusable versions or expendable ones; it is presently unclear how many times a reusable tug could be used.,

Ground facilities needed. If each orbiter is being re-launched every two weeks, generally one assembly facility and launch pad is needed for every two orbiters. This is because it takes one week (160 hours) to assemble and launch a given shuttle, meaning that only two can be launched from a given facility during a given two week period. This would mean that for the three scenarios, 1, 2 and 20 sets of assembly facilities and launch pads respectively would be needed each year for waste disposal. It should be noted that it takes about four years to build a new launch facility.[3]

Resource Requirements With Associated Bottlenecks in Acquiring These Resources For the Scenarios

At the various levels of effort outlined above, what resources would be needed, and what logistics problems with the U.S. might be encountered? Extraordinary resources needed would be negligible for the 10 launches per year scenario because that program could be included easily into the presently-planned regular shuttle program. Therefore, our attention here is on the 100 and 1000 launches a year options.

Problems of Orbiter Supply

Orbiters require about 30 months to build. At present two orbiters are under construction at Rockwell International's facilities at Palmdale, Southern California.[4] Thus, to provide the 4 orbiters required for the 100 launches a year program say, within five years from the start of the space disposal program, two space disposal orbiters plus at least one back-up orbiter would have to be under construction early in that period. Adding this additional production to the present construction rate of two orbiters at a time thus would mean more than doubling this present production. For the 1000 launches a year scenario, 40 new regular orbiters with perhaps another 5 back-up machines would be needed; to have them all in five years, i.e., deliver an average of 9 a year, 22 space disposal orbiters would have to be under construction at any given time. 22 space disposal orbiters plus 2 non-space disposal orbiters means 24 under construction at a given time, 12 times the present rate. If those 45 orbiters were wanted in 10 years, then 11 plus 2 would be under construction--roughly 6 times the present rate. In short, roughly 2 to 12 times as many resources--materials, construction facilities, personnel--would be needed, though of course increased orbiter production would bring some economies of scale.

The obvious question here is how quickly such an expansion of production could be undertaken without extraordinary strain on supplies and the economy. At the highest launch level scenario, it is a question of whether there would be enough resources in the country to do this type of expansion at all. In short, would there be "bottlenecks: here, constraints on expansion, and if so, where? Since we were able neither to obtain specific data on what kinds of resources are involved in building orbiters and related shuttle equipment, nor estimate how easy or difficult it is to expand supplies of these resources, we can only make a few general comments. Most obviously, a 12 fold increase in shuttle production would be a massive undertaking, with many logistics problems. Furthermore, these logistics problems could become politically important, since getting the resources would require special political action by the government. Finally, space disposal is a waste management option that is complex and requires large-scale equipment: thus it would be difficult to expand a space disposal system rapidly.

More detailed analysis requires that a separation between the construction and operational phases be emphasized. It is in the construction phase that a number of important changes would take place which would introduce considerable strain on economic and social patterns in the U.S.

Construction Phase

The construction phase of expanding space shuttle activities to accommodate a radioactive waste disposal mission involves problems concerning both the availability of materials as well as problems associated with personnel and the facilities themselves. Recent attention has been drawn to the types of material shortages that the U.S. aerospace industry currently is facing.

> [The n]ational commitment to energy independence and the production requirement of some military programs such as the McDonnell Douglas F-15 and Rockwell International B-1 are expected to lead to shortages of critical aluminum and steels, according to Commerce Department officials.[5]

Special note must be made of the effect of the Alaska oil pipeline and other planned pipelines, as well as increased construction in the railroad industry which increases the demand on material needed in the aerospace industry. This is particularly crucial since the orbiter structure is constructed primarily of aluminum, which is also used for such other shuttle components as the propellant tanks of the shuttle external tank. These material shortages could create serious "bottlenecks" in a large, growing space disposal program.

In a recent review of the space shuttle program,[6] there was an extensive discussion of the difficulties encountered in obtaining proper materials for the ceramic re-entry shield blocks. The nation's resource base for the pure materials needed was stretched to present limits, as were fabrication facilities adequate to the job. Even at present program levels, then, some resource constraints are being encountered. Similar problems in other resource areas are likely to appear if a rapid program expansion were undertaken.

In a more detailed analysis, it would be useful to give decision-makers more information on what specific materials bottlenecks could affect each of the two larger scenarios. Data needed to provide this policy-relevant information--and data that should be gathered in any future research on the space disposal idea--include: types, quantities, and qualities of the materials needed to build the shuttle equipment and ground facilities, especially rare metal alloys; percentage of the present total U.S. supply of a given material that would be needed by a given annual launch level especially the drain on supply if a program of 1000 launches per year were undertaken; important alternative uses for these materia , such as in the production of civilian and military aircraft; and technical and political difficulties in increasing the supplies of important but rare space shuttle related materials. It is obvious that heavy demand for materials could trigger unanticipated secondary effects such as those discussed in Parts III and IV.

Space shuttle construction facilities are also of signal concern. These facilities are essentially limited at present to the factories of Rockwell International and the other contractors and sub-contractors involved in constructing shuttle equipment and ground facilities. A central concern would be whether the U.S. aerospace industry could efficiently absorb a rapid expansion of space shuttle production. Specific information on this matter is nearly completely absent. Though it is likely that there may be some excess 1960s-built aerospace production capacity available in the industry, its extent could not be determined by our study team.

Future analysis on the space disposal proposal would require following data: types and number of facilities needed to build shuttle equipment, especially orbiters; specificities of needed facilities for each of the three scenarios; and how difficult and time-consuming it would be to expand present shuttle production, especially whether present idle capacity could be converted to shuttle work or whether whole new aerospace factories would be needed.

Availability of construction personnel presents another set of potentially difficult problems. The present space shuttle program employs about 45,000 construction workers, a number expected to stay fairly constant for the next several years.[7] In estimating the manpower requirement for the three scenarios, however, it is not reasonable to extrapolate this figure for the construction of two orbiters to a single linear project of some 500,000 workers working on some 24 orbiters necessary for the largest scale scenario. First, some economies of scale in production should be realized. Second, many of the present workers are designers and R&D specialists who should not be needed through the entire lifetime of a long-term, large-scale space shuttle production schedule. Still, a rapid or moderately paced expansion of shuttle production would require significant new numbers of personnel, including new engineers and increased numbers of presently rare specialty technicians, such as titanium welders. Since it often takes considerable time to train such skilled personnel, shortages of some type of workers would likely be a major bottleneck to a large, fairly rapid expansion of a shuttle-based space disposal program. Due to the extensive training to produce high quality aerospace engineers and technicians, shortages of these types of personnel could delay a large-scale space disposal program for years and take away personnel from other, perhaps equally important aerospace projects.

Manpower requirements therefore should have a high priority in future analysis of the space disposal option. Specifically, further analyses should be done on types and numbers of personnel needed to construct the shuttle hardware for a given space disposal scenario, the present total U.S. numbers of these types of personnel, how much time and money is involved in training additional personnel, and where the most critical bottlenecks are in the personnel picture.

Resources For Operations and Maintenance.

Once a space disposal program is built, it must be operated and maintained. Resources needed for operation are likely to pose substantially different problems from those prompted by the construction phase. Of course the magnitude of resources needed will vary according to the specific scenario.

Expendable operating materials, especially fuel, will require special attention. Each shuttle launch requires 99,800 kg (220,000 lbs) of liquid hydrogen and 603,300 kg (1,330,000 lbs) of liquid oxygen[8]; it also requires fuel for the solid fuel boosters. Serious obstacles to the rapid expansion to a large space disposal program would be present if it is difficult or very expensive to increase the production of liquid hydrogen and/or oxygen. Provision of spare parts for the shuttle orbiters, especially during overhauls also present such obstacles. Operating and maintenance personnel may be available from the pool of workers that would be employed in the construction of orbiters but this should be thorougly explored for there may be insufficient transfer of skill from one phase to the other. An estimate of 5,000 workers will work at the Kennedy Space Center handling these functions for the presently-planned shuttle program. Expansion would greatly increase this number. Financing requirements present another potentially formidable problem.

Capital. BNWL-1900 estimates the cost per flight of just a shuttle is about $10.5 million. However, every other flight in a space disposal program would include not just a shuttle orbiters but also a third stage; the cost per flight of a shuttle/reusable tug is about $12.5 million, shuttle/expendable third stage, about $16 million (1974 dollars)[9]. Thus a 1000 launches a year program would cost some $16 billion a year, in 1974 dollars; given inflation and cost overruns, the actual price could be much higher. The reason for such high costs is, of course, the large capital investment that shuttle hardware requires; for instance, a shuttle orbiter costs about $300 million. This financial requirement adds greatly to an economy already strained and forced with the prospect of huge capital outlays for energy production facilities.

Policy questions associated with the programs necessary to assure adequate resources. The fact that acquiring adequate resources might be a problem for a large, rapidly expanding space disposal program raises a major policy issue: what technical, management, and institutional steps could be taken to assure that adequate supplies of these resources are available to the program? A brief discussion of some of these issues follows along with some specific policy questions likely to be faced by NASA decision-makers in deciding to go ahead with space disposal options.

Four things can be done to help overcome a gap between the supplies of resources available and the amounts needed by the program: The first would be to develop new ways technologically to increase the supply of rare materials and personnel. For example, new methods should be pursued to produce and machine needed alloys or ceramics more easily, more quickly, in greater quantities, and perhaps even at lower unit cost. Developing such new methods often requires new R&D programs, which in turn require new management and institutional arrangements. One specific policy question raised here is what fields should any additional R&D be done, that is, what are the priorities in increasing the supply of needed resources? Second, new ways to cut the program's demand for particularly rare resources could be developed either by using more available substitutes or even technically eliminating the need for the resource altogether. For instance, if titanium welders appear to be in short supply, find a

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way to cut the number of welds needed per orbiter, or find a way to use other, more available welders. Additional R&D might be needed in this area. Third, increase the supply of resources available for the space disposal program could be increased, and thus assured, by cutting the demand other programs have for these same types of resources. In practice, this would be difficult, though NASA decision-makers should consider the possibility of working out resource agreements with other agencies and companies using the same materials. Finally, in the face of likely persistent shortages NASA could simply limit the program's rate of expansion, cutting down on its short-term demand for resources. An important policy questions is how much this strategy should be used, as opposed to using one or more of the above three resource strategies.

Because data has been unavailable to us we cannot make specific recommendations on which resource strategies NASA should use in the case of space disposal, or what R&D priorities it should set. Yet it is clear that for NASA decision-makers will likely be pressed to keep these kinds of "technically" related policy questions in mind.

Management-related aspects of the resources picture also raise important policy questions. NASA and the aerospace industry are already expert in the procurement of resources and their use in construction and operations. We shall simply re-inforce three major points about resource management of special relevance to the space disposal idea.

First, because of the unprecedented time span of the space disposal program (30+ years), NASA would need an unusually long-range resource planning capacity; it would need to identify long-term resource needs and then make recommendations to the rest of the program management concerning program expansion rates, procurement policies, and R&D priorities. The

The key policy questions here are on how to organize such a research planning capacity.

Second, the manpower and personnel matters deserve special attention from NASA. The agency traditionally has left manpower development to the corporate and educational sectors. But at least some NASA planning and supervision of personnel would be needed in a large space disposal program. Adequate numbers of skilled personnel would have to be assured. It is not clear that current reliance on corporate and/or educational sectors would provide such assurance. Therefore, scarce space disposal program funds may be needed to help train the personnel in special training programs. In these considerations it is likely that NASA will also be pressed to avoid a repeat of the boom-and-bust employment pattern which existed in the aerospace industry during the 1960's and early 1970's.

Third, a major management issue is likely to emerge concerning whether NASA should manage a space disposal program directly by itself, including direct management of resources, or whether the agency should turn part or all of the program over to a private contractor. NASA is traditionally an R&D agency; directly taking on a major operational program would involve major changes in both the agency's size, budgets, organization, and internal distribution of power and the "personality" and official role of the agency, both as seen from the inside and the outside.

The decision on whether or not to manage the program directly would have significant political consequences for NASA. Running the program directly gives the agency a degree of direct control it would not get with turning operations over to a contractor; yet it also means that NASA takes all the political criticism were there to be a major accident. Becoming a supervisor or regulator means that NASA takes only part of the criticism were there to be a major accident. Becoming a supervisor or regulator means that NASA takes only part of the criticism for problems; the private contractor takes the rest. However, if contracting means are used, some loss of control for NASA is likely to be added to increase confusion over who controls what facilities and how a contractor-run space disposal program fits in with a NASA-run regular shuttle program. An [illegible] to reduce [illegible] political pressure on the agency--but one which would increase the general confusion surrounding the space disposal option--would be to turn space disposal operations completely over to a contractor, with its regulation to be carried out by another government agency, such as the Federal Aviation Administration. This would take NASA off the hook for problems, but also means that, while it would limit NASA's role mainly to R&D thus limiting its overall role and foregoing a strong rationale for increasing agency funding, it would reduce both external political pressure and avoid the internal stress a program of such magnitude would stimulate.

Major institutions of our society such as federal governmental agencies, state governments, corporations, organized labor, organized religion, the educational "establishment," and foreign governments form significant sectors of NASA's environment. These institutions are large, long-lived, and powerful social groups. They are significant to NASA because they are the sources of considerable pressures and/or incentives for agency operations. Some--especially governmental agencies control NASA's purse strings, and set certain conditions on how the money is to be used. Others often play a major role in determining how well a program can or will perform, or, indeed, whether it will even exist at all. Labor unions can cripple NASA contractors. Congress can eliminate cutting off funds or withdrawing its authorization to take on additional missions.

There are a number of issues pertaining in the institutional and managements associated with space disposal of radioactive wastes. The most crucial issue is whether [illegible] NASA would be legally authorized to establish such a program. Other central issues include which specific U.S. institutions and [illegible] should have [illegible] over a space disposal program and what concessions the U.S. might grant to foreign powers in order to get their cooperation. Other chapters of this report discuss some of these issues. Here we briefly note some of the institutional issues associated with the acquisition and use of resources.

Legal authority and funding obviously is the initial need. Funding may be found either from private institutions such as banks or from the federal or state treasuries. But for programs such as the space disposal option which will be risky and expensive, private funding is highly unlikely. Public financing will be necessary and thus difficult issues of public policy arise. Should funding come directly from Congressional appropriations? If so, should the money be in the NASA budget or the FRDA budget? Or should some sort of trust fund be established, financed by levies on the users of nuclear-generated electricity? And if such levies are used, how can they be designed to be just and equitable? Furthermore, what methods can be used to keep cost overruns down, and who should pay the bill if the program only partially works and is cancelled or else supplemented with additional waste disposal programs?

A space disposal program, however, will very likely need more than authority and money to acquire the resources. Some of these resources will be in such short supply that a rapidly expanding program may need some sort of "priority claim" on such materials, facilities, and personnel, thus depriving other programs of adequate resources. Special institutional features then would be required to arrange such a set of priorities, something akin to a rationing and allocation scheme. Numerous specific policy [illegible], including [illegible] would be.

NASA could not establish an entire space disposal program by itself. Clear considerable inter-agency relations would be included. If nothing else, NASA would have to cooperate with the two main nuclear agencies, ERDA and the Nuclear Regulatory Commission. Special institutional arrangements, including inter-agency agreements, would be needed to facilitate such cooperation. Numerous specific policy questions arise here concerning the form of cooperation, how financing between agencies is arranged, and so forth.

As these various types of resource, funding, and institutional issues are settled, chains of activities will be set in motion. Many will result in significant changes--second order efforts--both within NASA and among existing governmental and industrial organizations and the experience of individuals and communities into which the operational activities of the program are carried out. Before we turn to a discussion of the second order impact let us examine the character of the official government attitudes and public attitudes toward the program. This will afford us an advanced insight regarding the kind of reception secondary impacts may receive as the program is evaluated and/or implemented.

NOTES TO CHAPTER 6

1. National Aeronautics and Space Administration, Lyndon B. Johnson Space Center, Space Shuttle, February 1975.
2. Phone conversation with Mr. Howard Roseman, Program Evaluator, Space Shuttle Program Office, NASA-HQ, Washington, May 3, 1976. It is unclear at this time how long a shuttle orbiter overhaul would take. However, six months does not appear to be an unreasonable estimate.
3. Information on the 160 hour turnaround time from Space Shuttle, p. 3; statement that there is about a four year lead time on new ground [illegible]
4. [illegible]
5. "Aluminum and Steel Shortages Predicted," Aviation Week & Space Technology, March 1, 1976, p. 19.
6. "Thermal Tile Production Ready to Roll", Aviation Week & Space Technology, Nov. 8, 1976, p. 51.
7. Roseman conversation.
8. Space Shuttle, p. 35.
9. High-Level Radioactive Waste Management Alternatives, Report #BNWL-1900, Battelle Pacific Northwest Laboratories, Richland, Washington, May 1974, pp. 8.41-8.42.

CHAPTER 7

POLICY AND REGULATORY ENVIRONMENT

__[illegible]__

[illegible] captured the attention of the policy making community in Washington in unprecedented ways. Not only have the Nuclear Regulatory Commission and the Energy Research and Development Administration increased their interest in the area, but they have been joined by the Environmental Protection Agency, the Council on Environmental Quality, the Office of Management and Budget, the Federal Energy Administration, and the Domestic Council. Radioactive waste has lost some of its non-glamorous character and become a hot issue. In this chapter, we will examine the political environment of waste management, focussing first on the Federal bureaucracy and then on outside stakeholders--including the nuclear industry and the nuclear critics. Their decision premises and constraints will be considered and assessed. A specific decision which has implications for the space disposal option, plutonium recycle, will be examined to show the problems that alternative for waste management faces in being adopted.

The dominant desire among all Federal agencies is to reduce the uncertainty which presently characterizes waste management policy. This uncertainty stems first from the lack of an adequate knowledge base to design the technological core of a waste management system. While there appears to be a general sense of confidence in the official positions of the Federal bureaucracy that such a system can be devised, no one is quite sure how to identify one when they see it nor do they know how to choose among a number of alternatives. Second, external political forces are increasing agency uncertainty. Nuclear critics are increasingly focussing their attention on the so-called "back-end" of the nuclear fuel cycle--particularly on plutonium recycle and waste management. This [illegible] a significant [illegible] their [illegible] strategy [illegible] concentrated [illegible] safety. This new interest [illegible] means that more resources will be devoted to developing technical critiques of agency actions and to preparing legal challenges to agency plans. Such behavior, of course, greatly destabilizes the political environment for the Federal agencies charged with developing and implementing waste management policy.

The Federal bureaucracy feels tremendous pressure to resolve the present uncertainty underlying waste management policy. The pressure is due partly to the increasing recognition that waste management has the potential for being an Achilles heel for the entire nuclear program. It is also due in part to the need to provide the nuclear industry with firm regulations required to design facilities for the back-end of the fuel cycle.

Given the uncertainties and the pressures to reduce them, it is hardly surprising that only a narrow range of technical alternatives for waste management is being pursued. The range is defined by two factors: Is the technology perceived as being virtually "one the shelf"? Is the alternative "cost effective"? It is clear that those two variables dominate the thinking of virtually all the agencies involved in the development of waste management policy.

Other factors, of course, do play some role in formulating specific agency positions. Both the Environmental Protection Agency and the President's Council on Environmental Quality are extremely concerned that any waste management proposal be directed toward ultimate disposal of the wastes. Interim solutions are criticized by these two organizations because they tend to postpone consideration of ultimate methods--perhaps indefinitely. EPA and CEQ both feel that such an outcome would be most unfortunate.

Until this last fiscal year, the Office of Management and Budget has not been lavish in its financial support for waste management programs. That behavior was due partly to their traditional approach to budgeting which held that if the agency itself does not seek more money, it is not the role of OMB to overwhelm the organization with largesse. Budget examiners at OMB, recognizing that their past behavior might have been shortsighted, justify it by arguing that the AEC itself never really pushed them to provide more funds. Although both ERDA and NRC have recently received major increases in their budgets for waste management activities, the OMB norm of guarding the treasury against profligate agencies remains. All proposals are given close scrutiny.

Two other Executive agencies, The Federal Energy Administration and the Domestic Council, have taken a recent interest in the development of waste management policy. They are primarily interested in quick implementation of some sort of a system. Neither is particularly sensitive to the positions of the nuclear critics. Both have emerged as major Administration forces pushing the development of nuclear power.

The Nuclear Regulatory Commission has the responsibility of licensing any system which ERDA develops for the ultimate management of radioactive waste. Within the Office of Nuclear Material Safety and Safeguards, waste management regulation has emerged as the top priority area during the last year. [illegible] of goals and objectives for waste [illegible] using a task force [illegible], representing a number of disciplines. Although their report has not been made public, a number of their ideas have already been adopted by the Commission. Two significant passages presented in testimony before the Joint Committee on Atomic Energy in April, 1976, suggest the important shift in the way the Federal bureaucracy has conceptualized the problem of waste management.

> The decisions we make today regarding the management of nuclear wastes must provide protection of the public far into the future. We cannot put off those decisions or actions to future generations or to unknown technologies. We who reap the current benefits of nuclear power must assume and fulfill responsibility for the effective handling of the problem of nuclear wastes.
>
> Among the ingredients for the safe management of nuclear wastes two that stand out are a trustworthy technology and a process for the timely implementation of that

> technology. The NRC program is addressing both. Having the technology on the shelf is not enough. Criteria are required for selection of optimum technologies and for their operation. Organizations must carry out the tasks. And these organizations must have commitment to follow through.

Although there will be criteria advanced for dealing with the technological core of the system, every indication suggests that the forthcoming statement of goals and objectives will focus on non-technological aspects, including the problem of error correction in the organizational infrastructure. The report will also address the issue of decision making with respect to waste management policy. It will suggest that the past attempts to reach decisions based on cost-benefit or benefit-risk analysis have been too narrowly conceived. Non-quantifiable factors such as the impact on civil liberties, it will be argued, must also be seriously considered by decision makers. The report will point out that we owe something to future generations. Some of the debts which are articulated are: not limiting their future actions, not spreading our risks to them without concomitant benefits, not overly limiting their resource base, and not imposing social systems upon them. Translated into design objectives for a waste management system, the need to fulfill responsibilities toward the future means that the system cannot depend on the continued existence of the commercial nuclear power system, that the establishment of the system cannot be deferred, and that the system shall not require stability of social and governmental institutions for its security and continued operation.

If the NRC has charted a new course in its waste management operation, ERDA has continued along much the same path taken by the AEC for the past twenty years. In the Spring of 1975, the Division of Waste Management and Transportation was abolished and a new fuel cycle division--of which waste management was just one part--was created. The intent of that organizational change was to provide better integration of the various elements of the nuclear fuel cycle. As a result of that bureaucratic shift a new director took over responsibility for waste management.

His views corresponded quite closely to those of his predecessor in all but one respect. The present director firmly believed it was foolish to place "all your eggs in one basket." Operationally that has meant that ERDA has committed itself to examining a number of possible sites for geological disposal of radioactive wastes. In addition to the salt beds in New Mexico, ERDA is investigating granite [illegible], salt domes in the Gulf states, and other geologic [illegible] in [illegible] United States.

Moreover, ERDA has increased its funding of the so-called advanced concepts such as seabed disposal. That alternative, in fact, has attracted a growing number of supporters within ERDA who view it as a means of not only solving the technological problem but of avoiding some of the potential political and organizational problems associated with land disposal of the wastes as well.

Nevertheless, the overwhelming push of ERDA is still in the same direction as the old Atomic Energy Commission. Efforts are being made to build and license a site in New Mexico's salt beds. So intense has been the pressure to get on with those efforts that even the Interior Department which presently administers the area has objected to the haste with which the project has been carried out. The intent remains, however, to have a facility capable of accepting high level commercial waste by 1985.

These differences and nuances in the various agency positions on waste management policy should not overshadow the great similarities in their attitudes. As suggested above, they are all constrained by two factors: Is the technology perceived as being "on the shelf"? Is the alternative "cost effective"? As a result, there appears to be an almost single-minded commitment among the Federal bureaucracy to some form of geological disposal.

The space disposal option is almost universally not taken very seriously in Washington today. The only reason that could be discovered for its being discussed at all stems from what must have been a casual remark by former AEC Chairman James Schlesinger. At a meeting just after the Lyons, Kansas project had been officially abandoned Schlesinger pressed his staff to come up with other alternatives for waste management. Among the ideas he suggested was a hole 10 miles deep in the earth and the space disposal plan. That latter idea is still kicked around from time to time. Yet, having interviewed virtually all the people primarily involved in formulating waste management policy, no one was prepared to support the concept. They all pointed to its high cost and unproven technology as the reasons for their rejection.

The only possible reason why these influentials might change their minds about the space alternative would be if there was a sudden increase in the responsibility this generation perceived it had for the welfare of future generations. Such a dramatic shift, however, could not originate in the bureaucracy. It would have to be initiated either in Congress or in the Office of the President. Neither of those two branches of government show any signs of adopting such a novel attitude. In short, despite the variety of emphasis and approach that is present in the Federal bureaucracy today, it seems unlikely that sufficient support for the space disposal option can be found. Absent of such support, the tremendous resources required to carry out the project will not be forthcoming. But if there is little support inside the government for the idea, is there enough outside to force a change?

One major outside stake holder is the nuclear industry. While there are some differences among utilities, vendors, and engineering firms on some side issues dealing with waste management, the nuclear industry has a fairly unified position on the major questions. Two considerations dominate industry's thinking. First, they need to reduce the uncertainty they are confronted with (technological, economic, and regulatory) as quickly as possible so that they can plan for the future. Second, the industry wants to minimize the costs of nuclear power so that that energy option is economically competitive with others.

Historically, the industry has often objected to additional regulatory requirements for waste management. There was, for example, substantial opposition to the adoption of Appendix F to 10CFR50 which required that high level wastes be solidified and transported to a Federal repository. Industry vehemently objects to the proposed regulation which limits the amount of transuranic contamination of materials buried in commercial waste management facilities to 10 nanocuries per gram. It has not, however, fought the idea of a Federally operated permanent disposal facility.

From these historical positions, we can infer the industry's response to the space option. We would expect them to be largely opposed because they would have to alter their present plans for dealing with the fuel cycle substantially, i.e., there would have to be partitioning of the high level waste stream and there could not be any plutonium recycle. Such changes would dramatically increase the already present uncertainty which the industry must con[illegible]. Some of that opposition to the space disposal option might be mitigated if the Federal Government paid all the costs of [illegible]. In such a case, the [illegible] to industry from not having to pay for space in a repository might begin [illegible]

The other major group interested in waste management policy consists of the nuclear critics. There are major differences among these. But on this issue there is considerable agreement. The leading force on waste management is the Natural Resoruces Defense Council. Their position is that it is risky and illogical to proceed with the development of nuclear power until there are greater assurances that a means for dealing with the long term waste management problems are at hand. They are extremely [illegible] can provide security for radiological dangers up to a [illegible] million years. Other critics range to an extreme position colored by their partisan opposition to nuclear power. If they were to concede that any technological alternative might, in fact, be viable, they would lose a strong aruging point in favor of their position.

It is hard to predict just what position the nuclear critics would adopt toward the space disposal option. On the one hand, they might be extremely skeptical about claims made for the system's technological **reliability. On the other, they would probably approve of the total removal of the material from the earth <u>if</u> a reliable system could be** demonstrated.

It seems clear, however, that no overwhelming groundswell of **support for the space disposal option exists today either inside or outside of the** government. The space alternative is perceived as just not being practical **at this time.**

Obstacles for adopting the space option are not limited to lack of support among influential decision makers. As we have pointed out in earlier chapters, the adoption of the space alternative is dependent on other decisions involving the nuclear fuel cycle. In particular there **needs to be a commitment in favor of partitioning the waste stream into the** shorter lived fission products and the longer lived transuranic elements. **There also must be a decision against plutonium recycle. In neither instance does it appear that the proper decision will be made.**

But what is more significant is the fact that in the consideration of these two decisions, the implications for the space alternative never even enter into play. The decision on plutonium recycle demonstrates this well.

<u>The Decision on Plutonium Recycle</u>

The issue of plutonium recycle (PUR) never captured much attention from the Atomic Energy Commission. No Commissioner ever had a formal or

even informal "lead" role in that area. In the first ten years of the agency's existence, no report about the question appears to have reached the Commission formally. In the quarter-century period extending to January, 1972, for which files are available, only fifteen documents dealing with plutonium recycle were ever even considered by the Commission. This lack of attention need not be equated with lack of interest or concern. It can be adequately explained in terms of the time periods involved. PUR had a relatively long time horizon; other matters had to be resolved, such as developing reactors, before PUR could become a salient policy question. Attention, therefore, was directed quite naturally to more immediate areas of concern.

This long time horizon also accounts for the slow development of the program. Nearly fifteen years were to pass from first inception to first commercial application. Its origins trace back to the work at the National Laboratory at Hanford, Washington in the middle 1950's. At that time, Hanford was operated for the AEC by General Electric. Shortly after research into PUR began, Commissioner Willard Libby requested the Director of the Division of Reactor Development to supply the rationale for the project:

> There are three principal reasons for undertaking an integrated program for the development of plutonium technology applicable to its use as power reactor fuels. These are as follows:
>
> a. Improved applicability of reactor technology based upon use of enriched fuels.
> b. Increased utilization of uranium resources.
> c. Eventual lowering of fuel costs.
>
> Perhaps the most pressing and immediate need for this technology arises from the United States' desire to assist other countries in the application of nuclear power for peaceful purposes...It is clear that other countries are reluctant to embark upon a large scale

> **nuclear power program based upon continuing feed from US uranium enriching plants. Recycling of the plutonium produced in thermal power reactors can reduce the dependency upon a supply of enriched uranium, and, in many cases, permit continued operation of the reactor on a natural uranium feed stream after an initial charge of enrichment.**[1]

Before PUR could become a reality several technical problem which affected the economics of the concept had to be resolved. Those included reactor physics, plutonium bearing fuel element development, and plutonium recovery process development. Hanford proposed the design and construction of two facilities to tackle those problems: the Plutonium Recycle Test Reactor and the Plutonium [Fuel] Fabrication Pilot Plant. The cost of the two units was estimated at $25 million. In 1956, the Commission approved the Hanford program. On November 21, 1960, the reactor went critical, that is, it achieved a controlled self-sustaining nuclear reaction. During that five year period, the AEC spent $21.5 million on operating and research costs in addition to the capital funds committed.

The nuclear industry, however, was hardly satisfied. In a letter to the then director of Reactor Development, Frank Pittman, written in 1962 by W. Kenneth Davis, Pittman's predecessor and now a Vice President of Bechtel Corporation, the complaint was made that: "At present [we] have no facts, only speculations of some highly technical advisors...This situation is bad in the United States; but it is proving to be a most formidable obstacle abroad in trying to utilize the slightly enriched reactors of US design."[2]

Despite the intent of the program to make US reactors and thereby US manufacturers more competitive abroad and despite Davis' protestations that he could think of "nothing more important to our overall reactor development program today than plutonium recycle," industry balked at taking on any significant role. In October, 1966, for example, Milton Shaw, now the Director of Reactor Development, noted in a memorandum to the General Manager: "While we have expressed disappointment with the rate at which industry has been picking up their part of the program, we are continuing our efforts to encourage them to do more and to achieve a smooth transition from the AEC-sponsored program to the industry-sponsored program."[3] A year later, the situation had not changed. Shaw, writing to the Commission, reported that the "industry sponsored plutonium recycle programs are not responsive, in terms of both scope and timing to the requirements which will exist by the early to mid-1970's."[4] The time horizon, perceived a decade before as being long-term, had by now shrunk significantly as a result of inaction coupled with the rapid increase in light water reactor commitments and the amount of plutonium expected to be discharged. Coping with those domestic challenges now overshadowed exports as the prime rationale for PUR.

But the failure of the nuclear industry to act in the face of those problems was not the only constraint affecting the future direction of the Commission's PUR policy. The Joint Committee on Atomic Energy (JCAE) was becoming increasingly restive with continued AEC involvement in light water reactor technology. In their report on the AEC Authorization Bill for FY 1969 the Joint Committee stressed the importance of phasing out Commission participation in the PUR program as soon as possible. The following year the JCAE reiterated its "oft expressed belief concerning the importance of private industry taking on the lion's share of the significant work that remains to be done in the plutonium recycle area."

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The agency, then, was caught between a reluctant industry and an increasingly irritated Joint Committee. After nearly two years of negotiation and pressure on the part of Milton Shaw, the industry, represented by the Edison Electric Institute (EEI) proposed a modest program to shoulder responsibility for PUR. EEI along with Westinghouse and General Electric would fabricate and irradiate mixed uranium and plutonium fuel rods in commercial reactors. Slightly more than $8 million would be spent over a period of five years. The proposal was conditioned upon the AEC reducing its base charge for plutonium from $43 per gram to just over $9 per gram. That alteration would provide a savings of over $1 million for the industry. While Shaw recognized that the price change might be opposed by the Commissioners or the [illegible] for a [illegible] program, he was in no position to [illegible]. The industry proposal was accepted in early 1970; direct AEC involvement in PUR development was by and large terminated at the end of that year.[5]

Up to now, the regulatory side of the Commission had little, if any, influence on the course of PUR development. On April 18, 1969, however, the regulatory side took its first action on plutonium recycle; it accepted an amendment to the technical specifications of the Big Rock Point Reactor in Michigan. The changes permitted the reactor--chosen as part of the industry-run program--to operate using fuel bundles containing mixed oxide fuel rods. The license was simultaneously amended to permit the Consumer Power Company which owned the reactor to possess and use up to fifty kilograms of plutonium in the mixed oxide fuel.[6]

Three and a half years later, the Company applied for and received another license amendment which allowed it to increase its use of mixed oxide fuel by a factor of three. In March, 1973, the West Michigan Environmental Action Council (WMEAC) requested AEC for a hearing on the amendment and filed suit in Federal District Court for the Western District of Michigan seeking declaratory relief and an injunction against the loading of additional mixed oxide fuel at the Big Rock Point Reactor. The court denied the injunction because the Commission agreed to a hearing and because Consumers deferred implementation of their plans to use more than fifty kilograms of plutonium in the Spring, 1973 loading of the reactor. The following year, however, in a second round of litigation WMEAC received a commitment from the AEC that the agency would consider the effect of the plutonium fuel cycle in a generic proceeding and that a Generic Environmental Statement on Mixed Oxide Fuel (GESMO) would be developed.

GESMO was released in August, 1974. In the document, the AEC staff concluded that the adverse environmental and safety consequences associated with using plutonium as a reactor fuel were small. Thus, the staff judged the problem of safeguarding the plutonium from diversion as being a "manageable one," and recommended the PUR be approved. They did indicate that a more detailed safeguards program would be developed in the next year or so, but saw no reason to defer the basic PUR decision until that point in the future. The Commission failed to resolve the PUR question finally in the remaining five months of its existence.

On January 20, 1975, just one day after NRC came into existence, Russell Peterson, Chairman of the Council on Environmental Quality (CEQ) sent a letter to William Anders, the new head of the NRC. The letter expressed the following view:

> Although the draft environmental statement is well done and reflects a high quality effort, it is incomplete because it fails to present a detailed and comprehensive analysis of the environmental impacts of potential diversion of special nuclear materials and of alternative safeguards programs to protect the public from such a threat.
>
> The Nuclear Regulatory Commission, the Executive Branch, the Congress, and the American people should have the benefit of a full discussion of the diversion and safeguards problem, its impacts, and potential mitigating measures, before any final decisions are made on plutonium recycle.
>
> The Nuclear Regulatory Commission should take care to avoid actions which would foreclose safeguards alternatives or which would result in unnecessary "grandfathering" during the period in which the safeguards issue is being resolved.

The letter had a profound effect on the fledgling NRC; it promoted a major review of the former Commission's plans for reaching an affirmative decision on PUR.

On May 6, 1975, the new Commission announced its tentative judgement on how the PUR decision should be made.

> On the basis of its consideration to date of the relevant factors, the Commission is provisionally of the view, subject to consideration of comments to be received, that a cost-benefit analysis of alternative safeguards programs should be prepared and set forth in draft and final environmental impact statements before a Commission decision is reached on wide-scale use of mixed oxide fuels in light water nuclear power reactors. The Commission is also provisionally of the view that in light of the variety of factual situations and legal considerations that may be presented, as well

> as the right to and reed for appropriate participation in the decisionmaking process by parties to the individual proceedings, the matter of deferral of future licensing actions which are related to the wide-scale use of mixed oxide fuels should be addressed within the context of the individual licensing proceedings. It is the Commission's provisional view that the following guidelines should be observed in resolving the deferral issue in such proceedings: (1) there should be no additional licenses granted for use of mixed oxide fuel in light water nuclear power reactors except for experimental purposes; and (2) with respect to light water nuclear power reactor fuel cycle activities (activities other than nuclear power reactor construction and operation) which depend for their justification on wide-scale use of mixed oxide fuel in light water nuclear power reactors, there should be no additional licenses granted which would foreclose future safeguards options or result in unnecessary "grandfathering." This would not preclude the granting of licenses for experimental and/or technical feasibility purposes.

The Commission estimated that a final decision on MOX could be delayed for as long as three years. The [illegible] was, in effect, a trial balloon. Recognizing the controversial nature of its choice, the Commission offered interested parties the opportunity to comment on that provisional decision. The Commission held meeting with representatives of industry and the general public to clarify any questions those groups might have. Over 200 comments--more than twice the number received at the initial publication of GESMO--were contributed by members of Congress, industry groups, utilities, and environmental organizations.

On November 12, 1975, the Commission handed down its final decision which contained four basic elements:

> 1. A cost benefit analysis of alternative programs for safeguarding plutonium mixed oxide fuel and facilities which handle them will be prepared on an expedited basis and published for comment as a supplement to the overall Environmental Statement on Mixed Oxide Fuel.

2. The public will have the opportunity to further participate in the ultimate decision by commenting on the safeguards supplement and proposed rules and by participating in hearings.

3. Eligibility criteria have been established for interim licensing of related fuel cycle activities... pending a Commission decision on wide-scale use. The criteria require consideration of such factors as the dependency of individual facilities on wide-scale use of mixed oxide fuel, possible foreclosure of safeguards alternatives, and the impact on the overall public interest of delays in licensing.

4. Operating licenses and amendments to operating licenses may also be issued which authorize the use of mixed oxide fuel in light water power reactors.

A new schedule for reaching a substantive decision on PUR was also devised. By speeding up the staff's [illegible] during the beginning of 1975 and by holding a parallel set of hearings--one on the safety, health, and environmental issues and the other on safeguards questions--rather than a single hearing almost fifteen months could be shaved off the original estimate of when a final decision on PUR would be made.

The final act in this extended history of the PUR decision came in June, 1976. The Natural Resources Defense Council spearheaded a court attack on the Commission's November, 1975 final ruling. The Second Circuit Court of Appeals ruled that the Nuclear Regulatory Commission violated its NEPA mandate by agreeing to license PUR dependent facilities on an interim basis before the entire Environmental Impact Statement -including the part on safeguards--could be finalized.

As the reader can see from this discussion, the debate over whether or not to proceed with plutonium recycle never directly involved the issue of what the implications might be for alternate choices of waste management, Indeed, the waste management programs of ERDA were predicated on the existence of reprocessing and PUR. As a result, options such as space disposal may very well lose whatever viability they may possess on the basis of judgments made in an entirely separate area.

Notes to Chapter 7

1. Plutonium Recycle Program at Hanford, AEC 960, March 14, 1957, p. 1.
2. Letter, Davis to Pittman, July 9, 1962.
3. Shaw to Hollingsworth, October 28, 1966, p. 1.
4. Shaw to Commission, October 24, 1967, p. 1.
5. See the following memorandum and Commission documents: Shaw to Hollingsworth, Lease of Plutonium for Irradiation in Dresden I Reactor, October 28, 1966; Shaw to Commission, Meeting With EEI Committee on Nuclear Fuels to Discuss Plutonium Recycle R&D Programs, October 24, 1967; Shaw to Commission, AEC-EEI Meeting of Plutonium Recycle, November 2, 1967, December 27, 1967; Industry Sponsored Plutonium Recycle Programs, AEC 960/11, January 31, 1968; AEC Supply of Pu for EEI-Sponsored Pu Recycle Program, AEC 960/13, July 22, 1968; Shaw to Hollingsworth, Plutonium Recycle Program Proposal by Edison Electric Institute (EEI), October 9, 1969.
6. Amendment No. 3 to Operating License No. DPR-6, April 18, 1969 and Change No. 17 to the Technical Specifications of Operating License No. Dpr-6, April 18, 1969.

CHAPTER 8

PUBLIC ATTITUDES TOWARD SPACE DISPOSAL OF RADIOACTIVE WASTES

One dominant theme stands out clearly in the history of the Federal Government's attempt to implement a waste management system: any option which does not find public acceptance will, regardless of its technological merit, not be adopted. The experience at Lyons and the story of the Retrievable Surface Storage Facility (RSSF) both provide striking evidence for that claim. Thus, any future plans to develop a space disposal system must recognize the significance of the public acceptance factor and take it into account.

This section attempts to provide a preliminary estimate of what public attitudes toward the space disposal option might be. It must be stressed that the estimate can only be a very approximate one. For one thing, it is based on data which did not address the issue of space disposal directly. For another, the estimate has had to be made before any firm program has been proposed or any details of possible plans have been made public. Clearly once that occurs the entire complexion of the issue will have changed and any predictions made herein about public reactions will have to be carefully re-assessed. Thus, the only question that this section can reasonably address is a limited one: are there indications that public attitudes toward the space option are such that it has a hope of being accepted?

Over the years a number of studies have been made about public attitudes towards nuclear power. Utilities and vendors have conducted several public opinion surveys. For the most part, however, the data gathered has not been made public. Several studies, undertaken by academics, have probed public opinions about nuclear power--often as part of larger studies dealing with public attitudes towards highly complex technological systems. In the last year, two studies about public attitudes toward nuclear power have been released. The first, done by the Batelle Northwest Laboratories,[1] focusses primarily on the issue of nuclear waste management. The second, undertaken by Lou Harris for the architect-engineering firm EBASCO,[2] deals more generally with the entire range of issues now surfacing in the great nuclear debate. Those two studies provide the core of data from which inferences about public attitudes toward the space option are drawn.

PUBLIC VALUES ASSOCIATED WITH NUCLEAR WASTE DISPOSAL: BNWL-1997, June 1976.

A total of twenty two groups, comprising 465 persons, from five regions of the U.S. were interviewed. The groups were aggregated to yield six sets of respondents: environmentalists, nuclear technologists, junior and senior high school students, public utility employees, church and civic organization members, and university students. Those final groups contained as few as 32 people (public utility employees) and as many as 164 respondents (university students.) The survey was administered by group with the respondents writing their answers down on a form provided. Before the survey was answered, the respondents viewed a fifteen minute film which provided reasonably accurate and unbiased information about nuclear wastes and the problems associated with its management.

The survey questionnaire was designed to obtain social value information about the relative importance of four aspects of nuclear waste disposal as well as information concerning some broader issues associated with the subject of nuclear waste disposal. The four nuclear waste disposal aspects or factors which formed the backbone of the questionnaire were described as follows:

Short Term Safety: Those risks involved in the storage, transportation, and emplacement of nuclear waste materials. These risks are largely borne by the people who used the electrical power which created the wastes. These risks would occur during a few years following the creation of the waste.

Long Term Safety: That portion of total risk which begins after the wastes were finally emplaced or disposed and which would continue for the next 250,000 years. These risks would be due to geologic changes and other "Acts of God" and possibly to negligence by man.

Cost: The dollar cost required by a given waste disposal method.

Accident Detection and Recovery: Steps that could be taken to reduce the consequences of an accident if it does occur after final disposal.

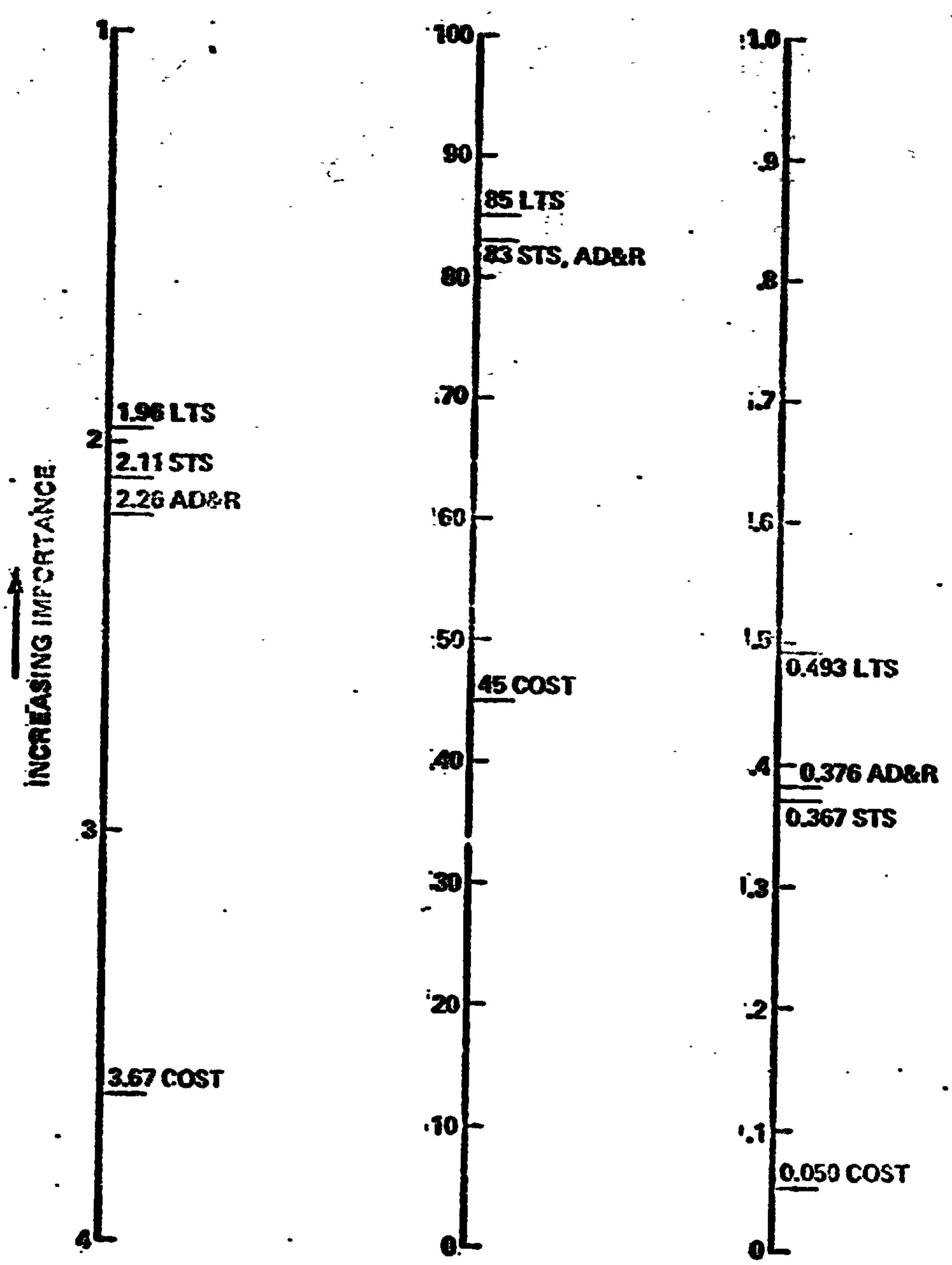
The study assessed the importance of each of those criteria in four ways. First, the respondents were asked simply to rank order the different factors, i.e., most important...least important. Second, the people interviewed were required to assign a number from 0-100 which reflected the relative amount of weight they felt each of the criteria ought to have in selecting a waste management system. Third, each person was presented with twenty seven charts each of which represented a hypothetical waste management system. In each chart the four factors were variously listed as having "high," "medium," or "low" scores. The respondent then assessed the acceptability of such a designed system. The assessment was the dependent variable and the score on each of the four factors was the independent variables. Regression coefficients were then calculated. The higher the coefficient, the more important the factor was perceived to be. Fourth, each respondent was asked to construct a system which would be minimally acceptable to him.

Only data for the first three methods were reported in detail. This is because the fourth method (minimally acceptable) appeared to measure something different than the first three. The three reported methods yielded substantially similar results. (Figure 8.1) Long term considerations were the most important. The degree to which they dominated varied from method to method. Short term consideration and accident detection and recovery were somewhat less important in the samples' collective opinion. Cost factors were significantly less central in assessing a waste management system. When the six sub-groups were analyzed separately some important distinctions emerged. Environmentalists placed significantly more emphasis on long term concerns and nuclear technologists placed significantly more importance on short term considerations than did the sample as a whole. (Figures 8.2-8.4)

In addition to the questions dealing with the importance of the four factors, questions were asked which attempted to measure acceptability of various performance levels for each of the four factors. Short term fatality rates of one death per fifty years, one death per ten years, and one death per

Figure 8.1

COMPARISON OF
AVERAGE IMPORTANCE ESTIMATES
FROM THREE MEASUREMENT METHODS
(TOTAL SAMPLE)



Source: BNWL-1997

WOOD

Figure 8.2

AVERAGE RANKINGS FOR SIX RESPONDENT CLUSTERS

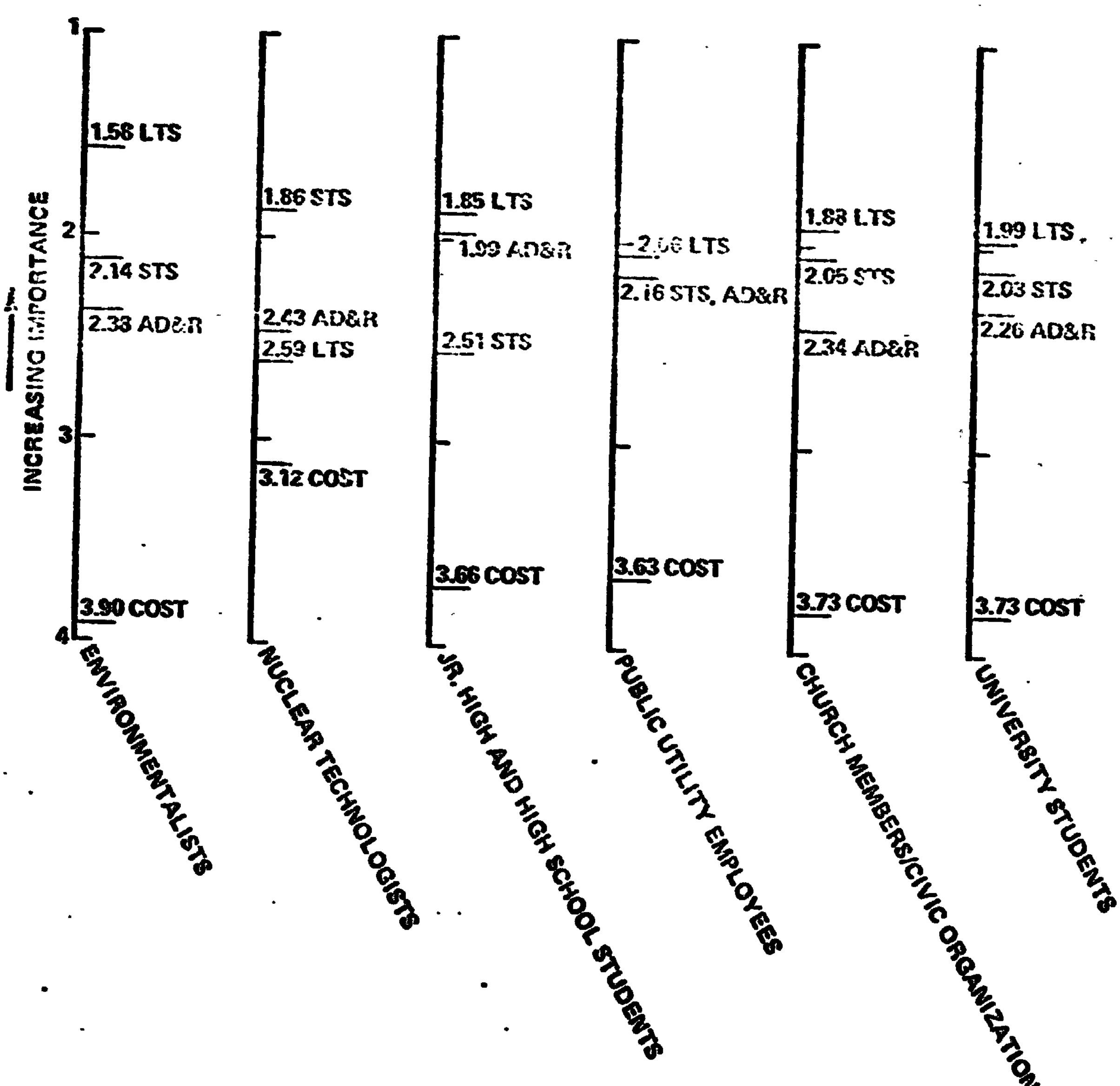
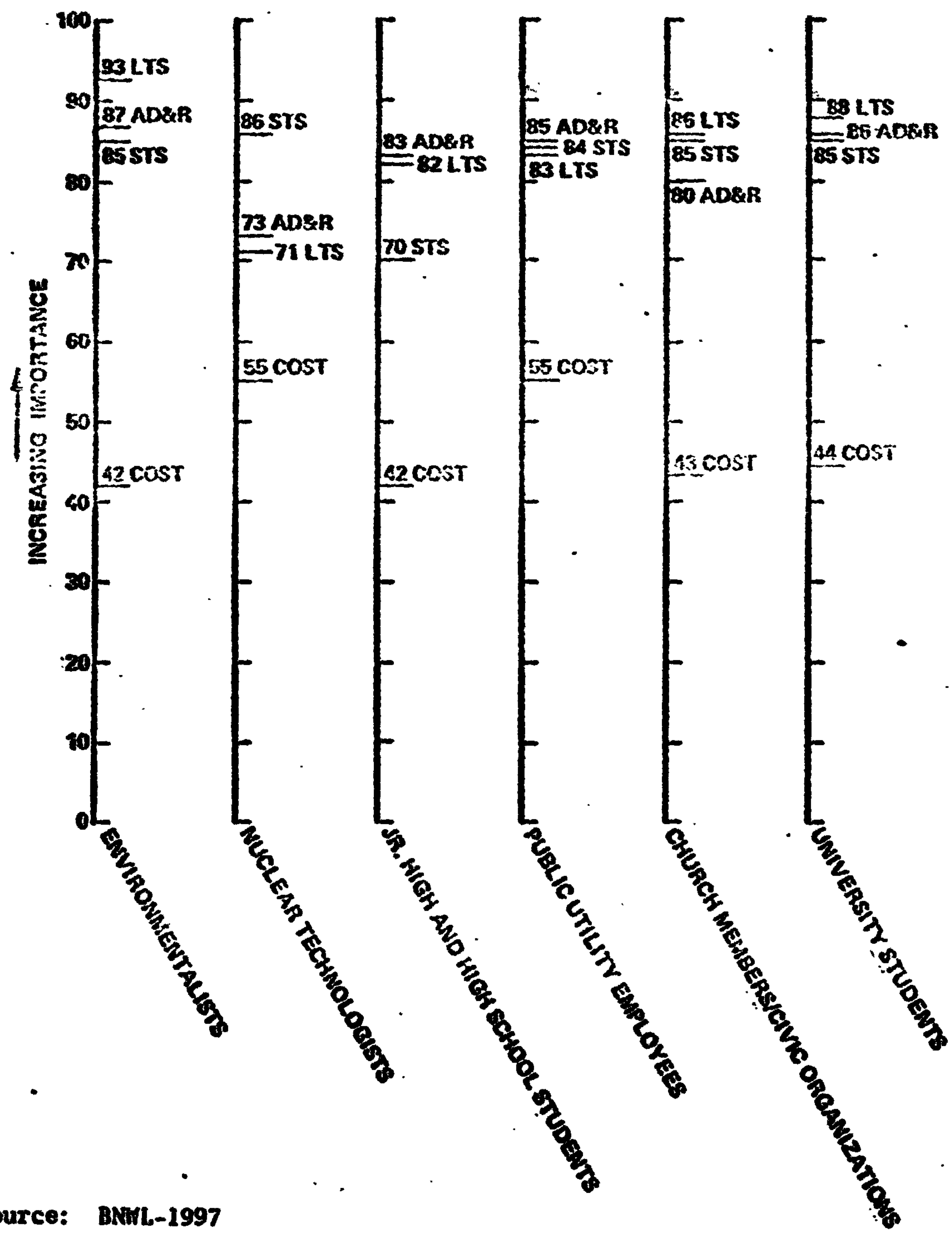


Figure 8.3

AVERAGE RATIO ESTIMATES OF IMPORTANCE
FOR SIX RESPONDENT CLUSTERS



Source: BNWL-1997

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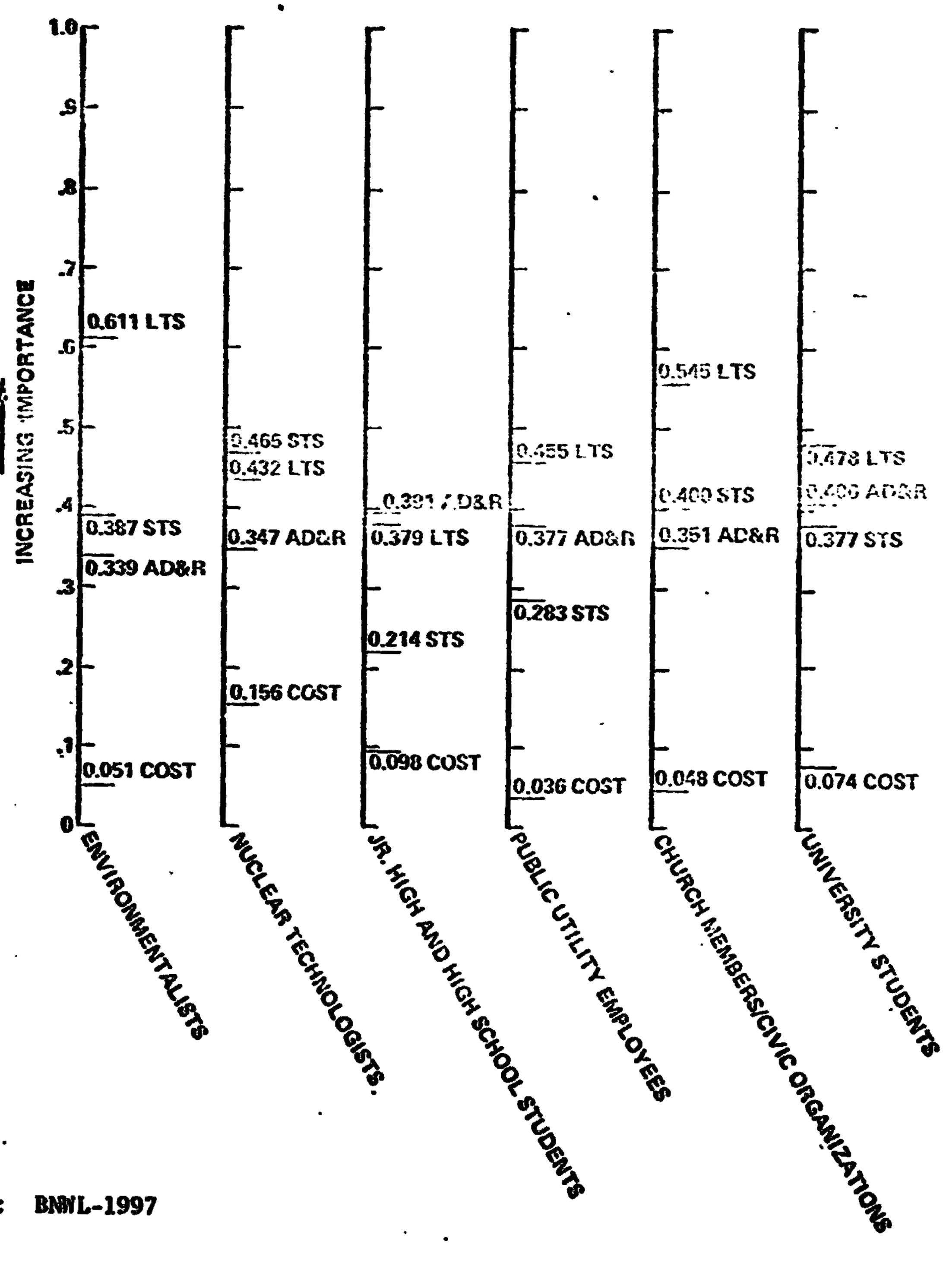
Figure 8.4

AVERAGE MULTIPLE REGRESSION WEIGHTS

FOR SIX RESPONDENTS CLUSTERS



Source: BNWL-1997

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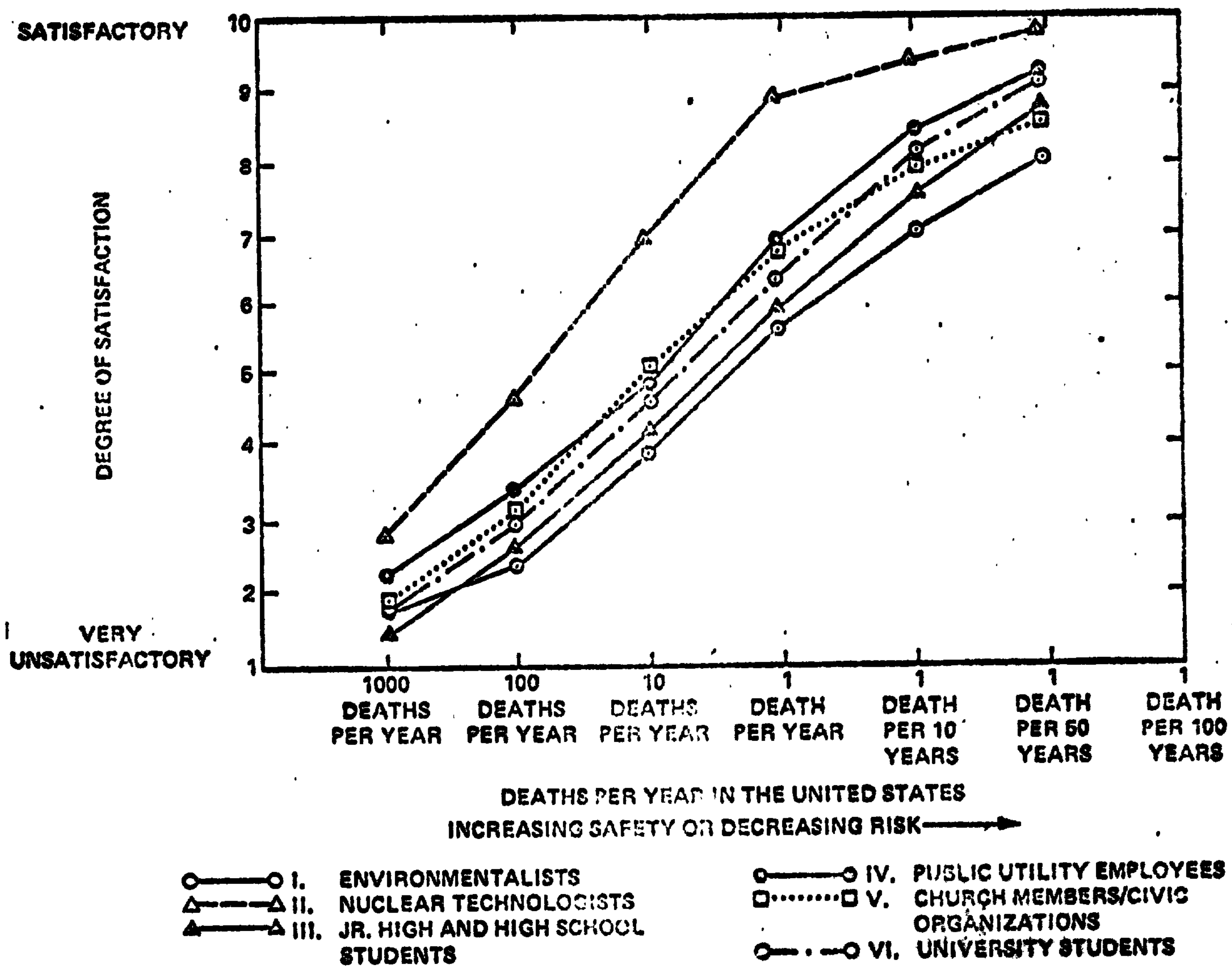


Figure 8.5

SHORT-TERM SAFETY

Source: BNWL-1997

WOOD

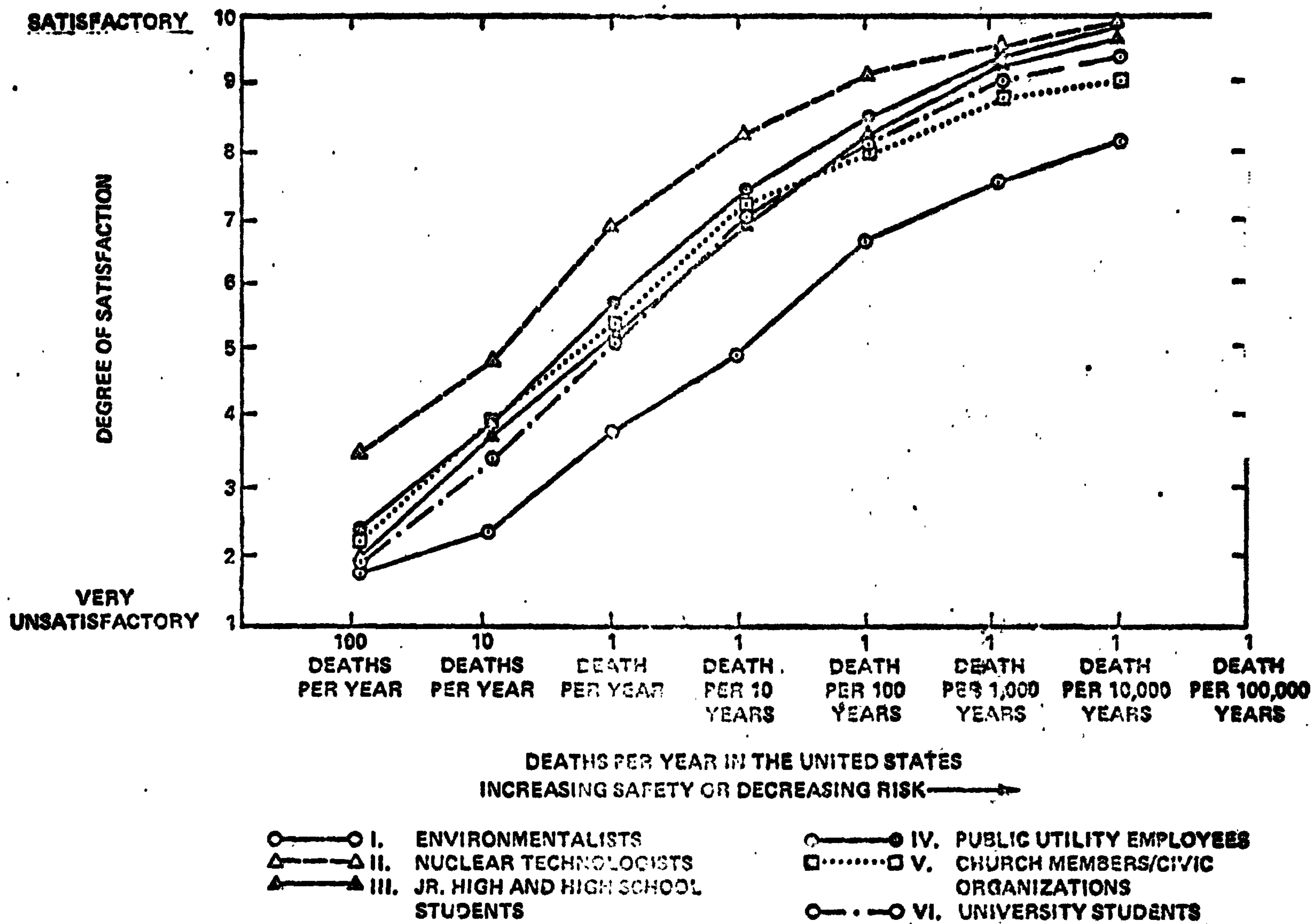


Figure 8.6

Source: BNWL-1997

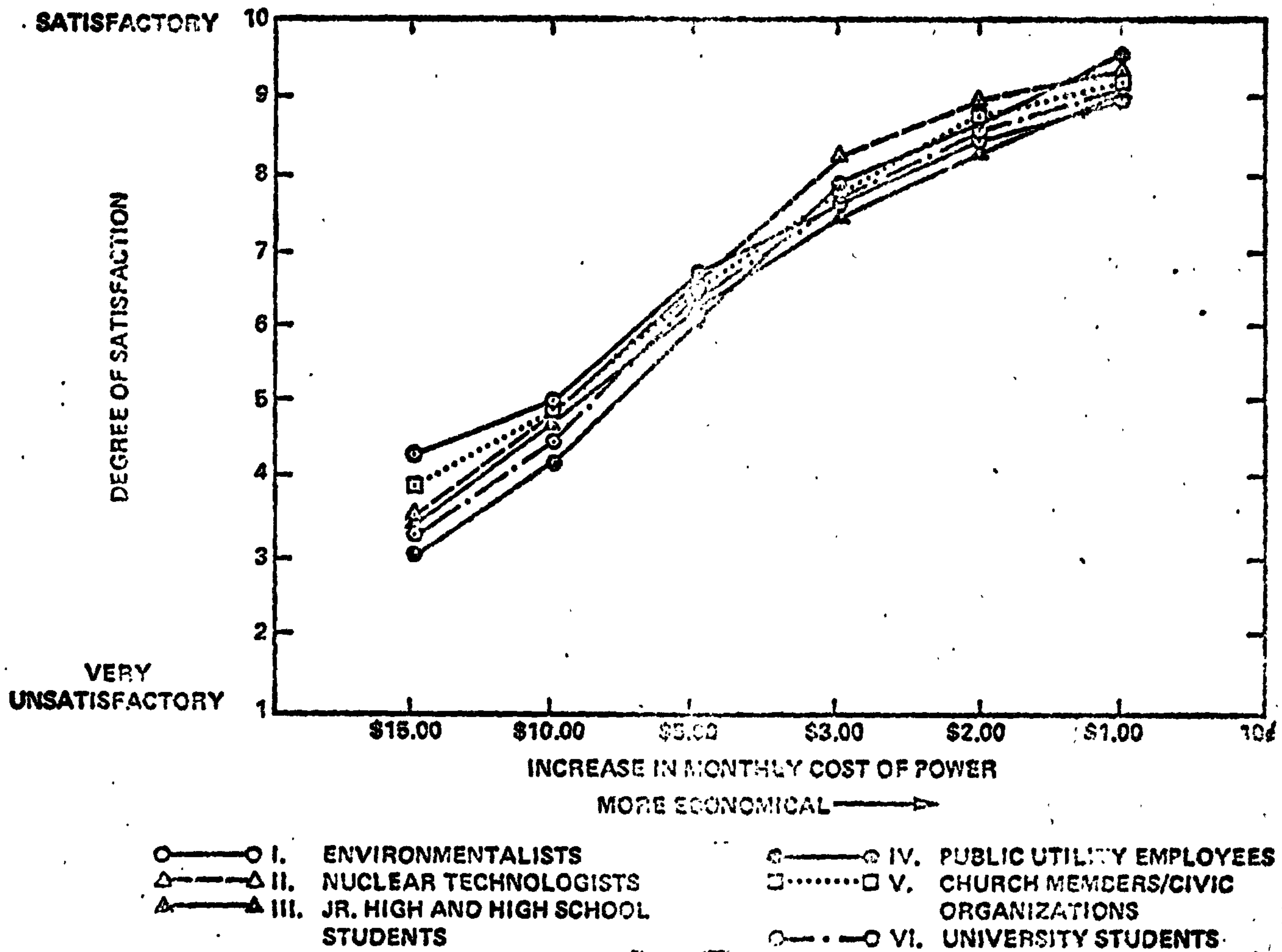
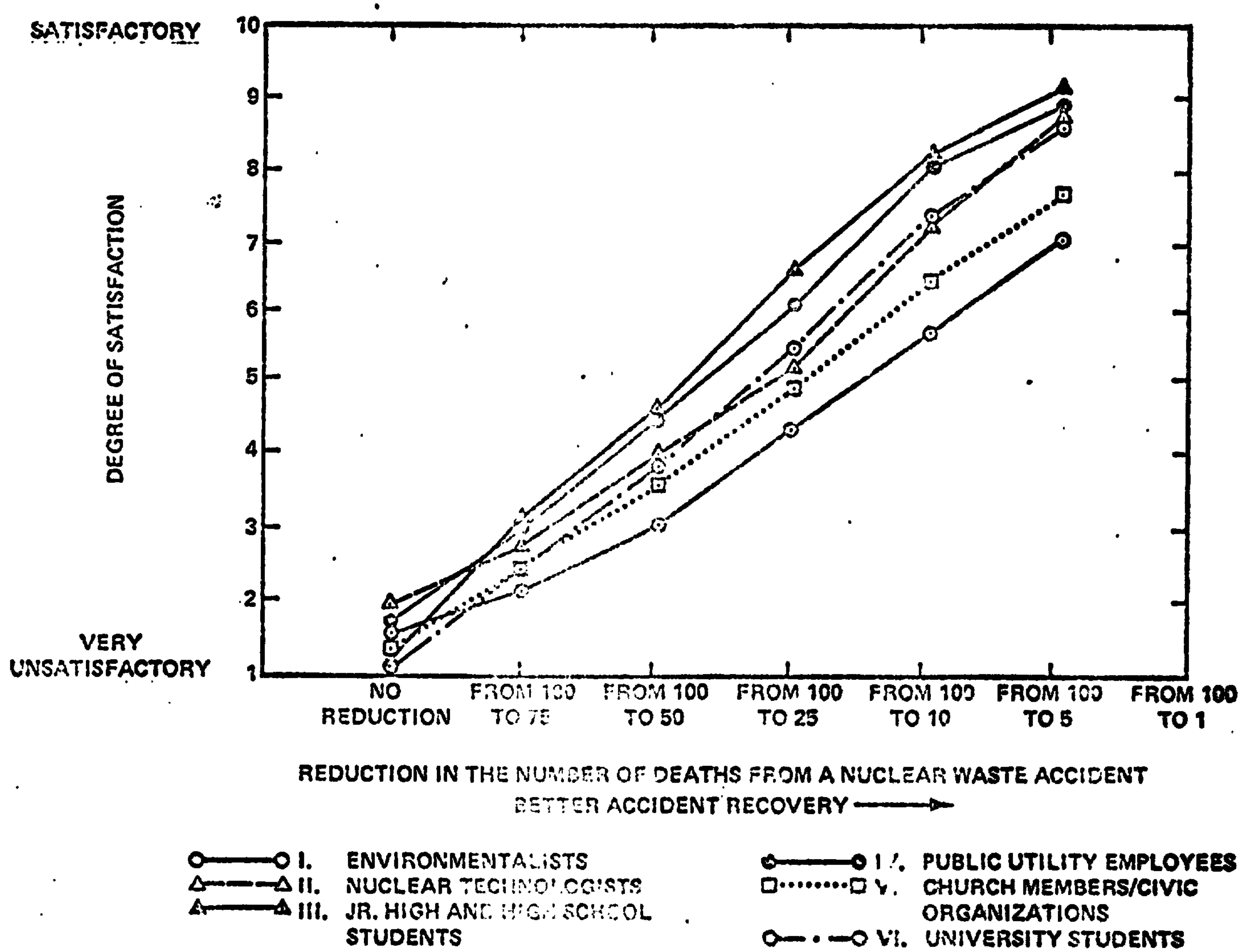


Figure 8.7

Source: BNWL-1997

COST

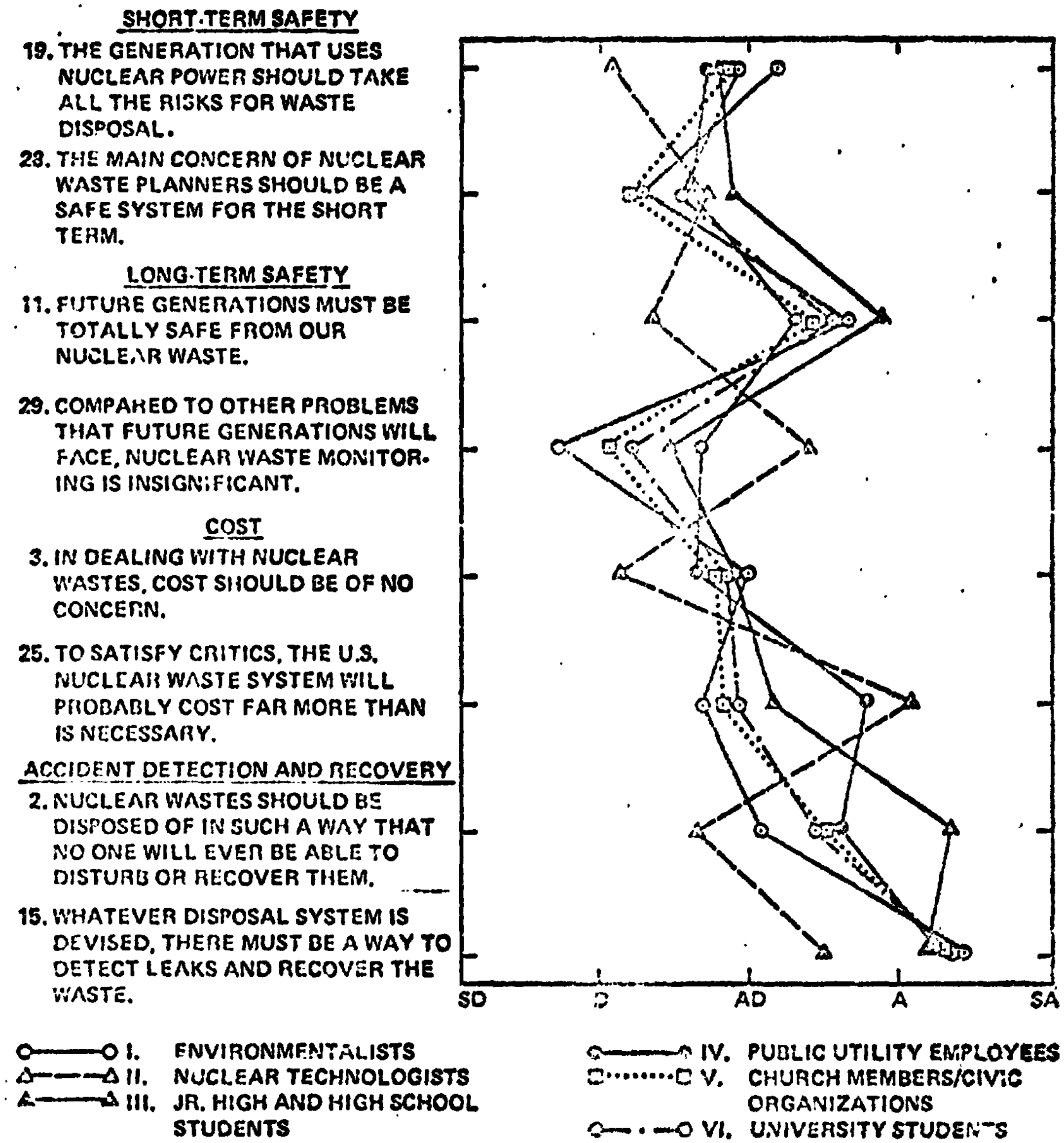


Source: BNWL-1997

Figure 8.8

ACCIDENT DETECTION AND RECOVERY

WOOD



Source: BNWL-1997

Figure 8.?

WOOD

Source: BNWL-1997

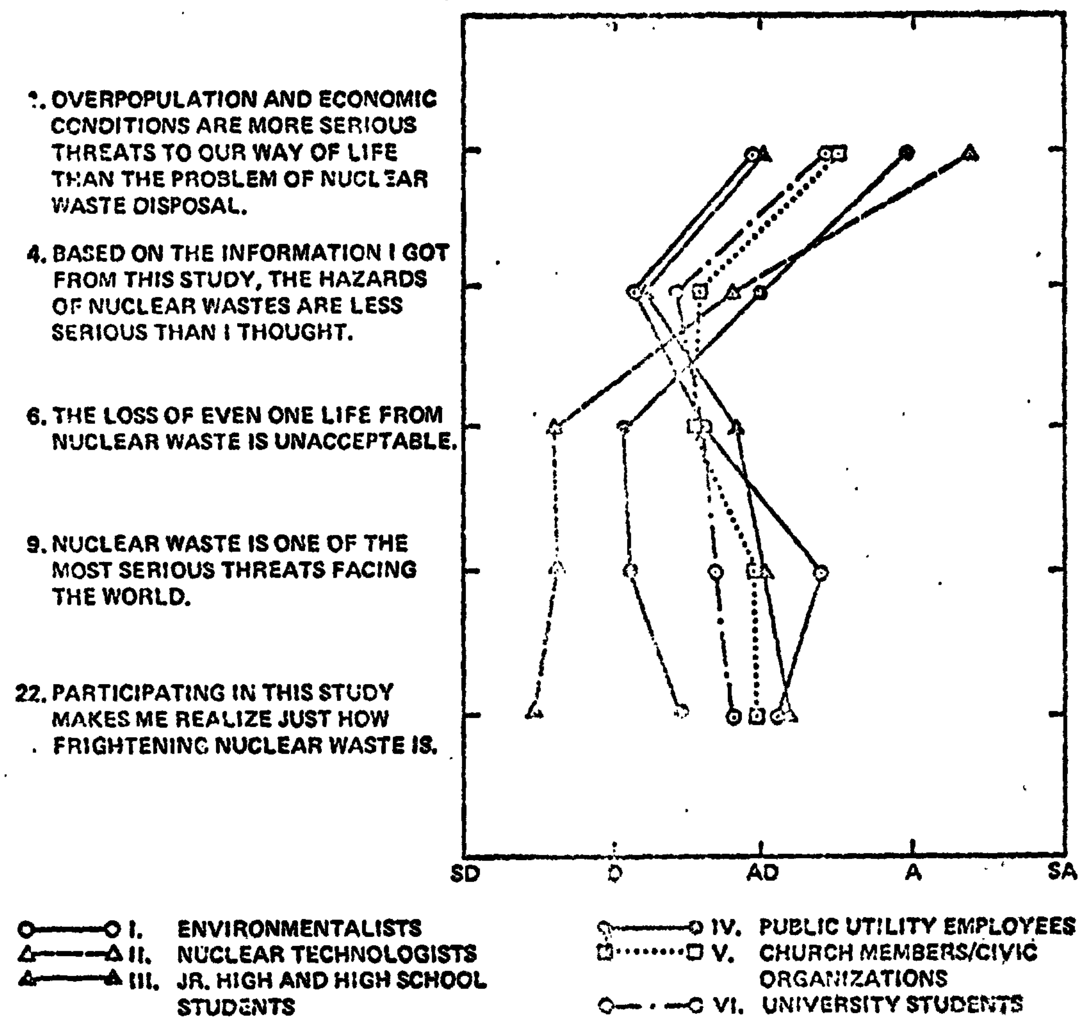


Figure 8.10

WOOD

PERCEIVED SEVERITY OF NUCLEAR WASTE PROBLEM

Source: BNWL-1997

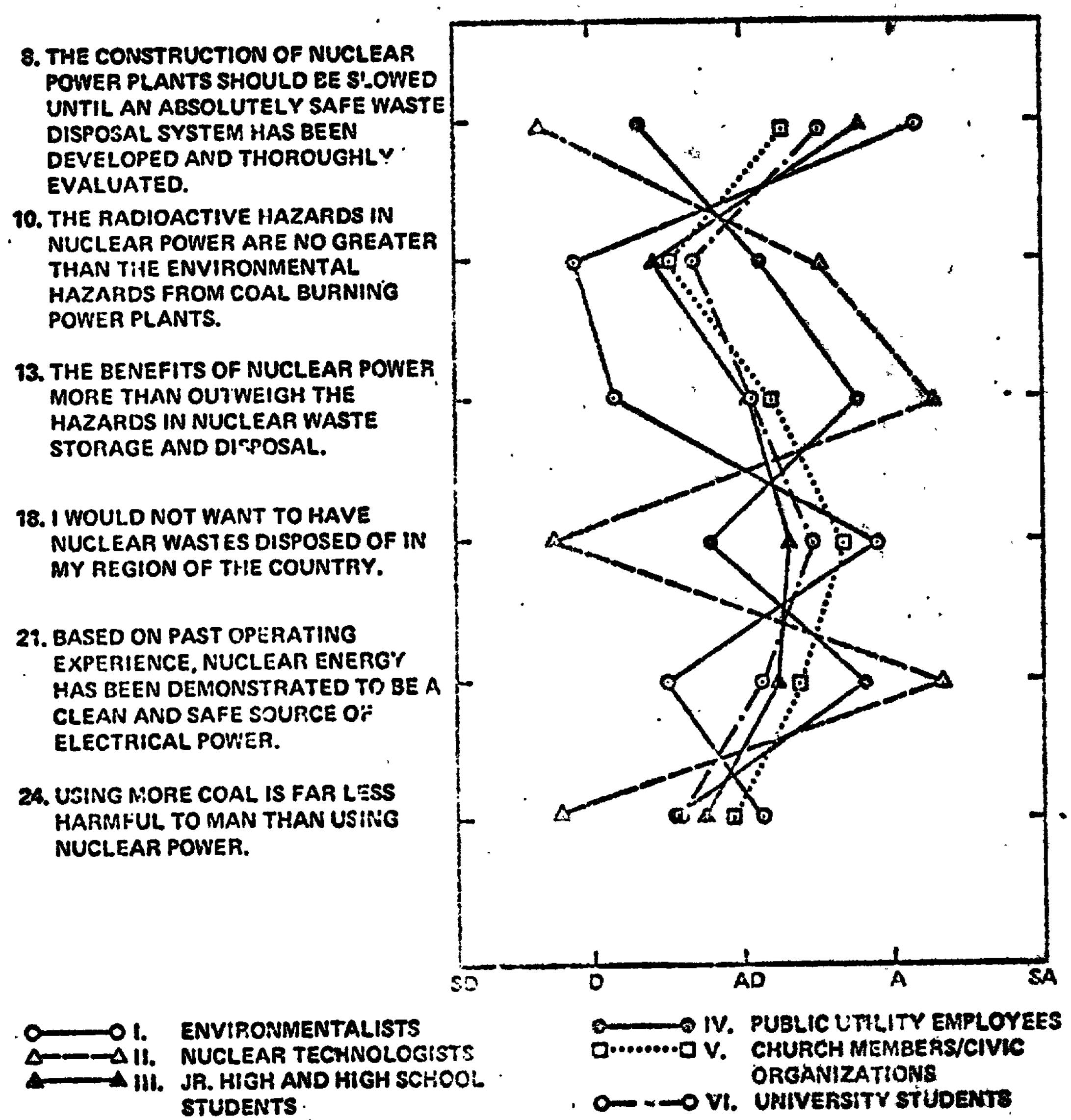


Figure 8.11

WOOD

PERCEIVED SAFETY OF NUCLEAR POWER

Source: BNWL-1997

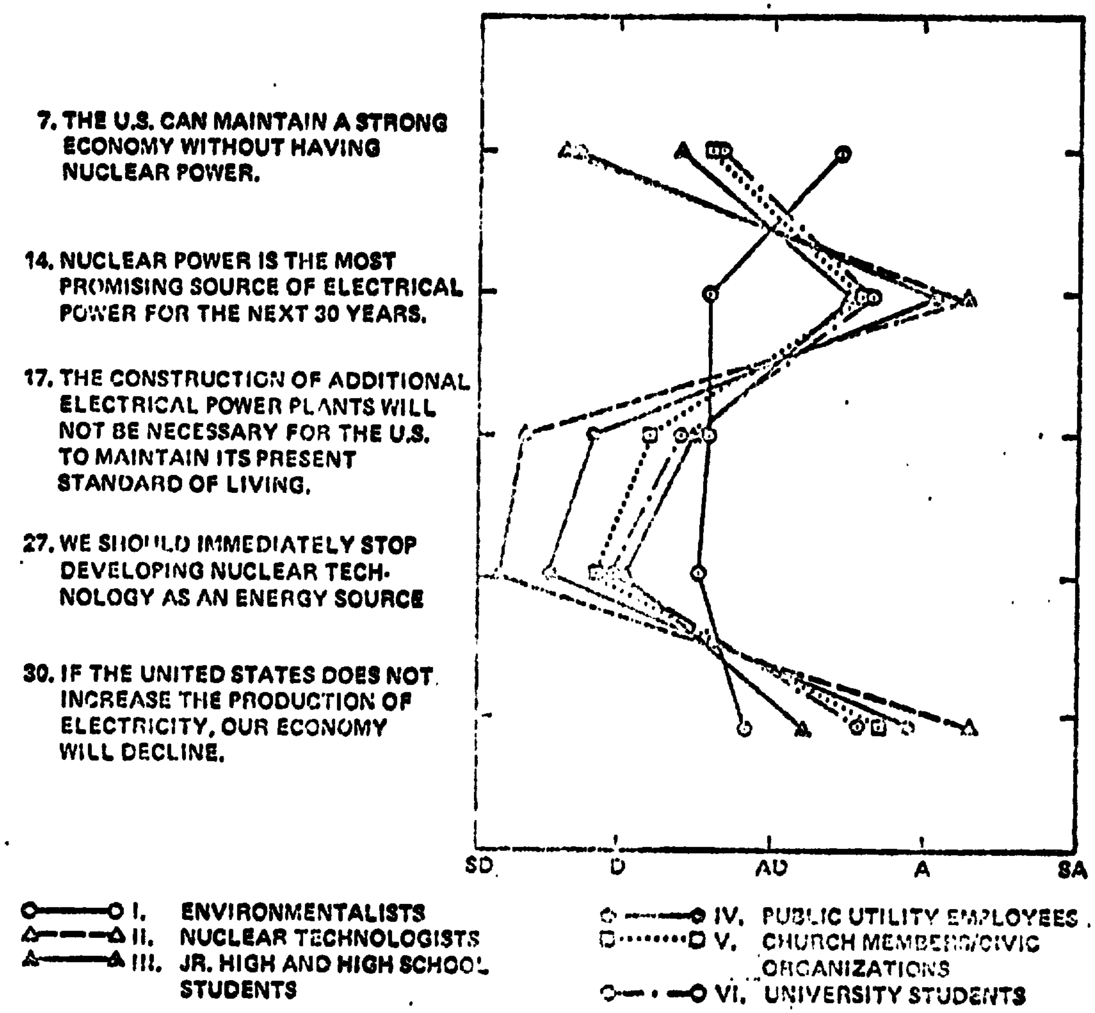


Figure 8.12

WOOD

PERCEIVED NEED FOR NUCLEAR POWER AND NEED FOR POWER IN GENERAL

Source: BNWL-1997

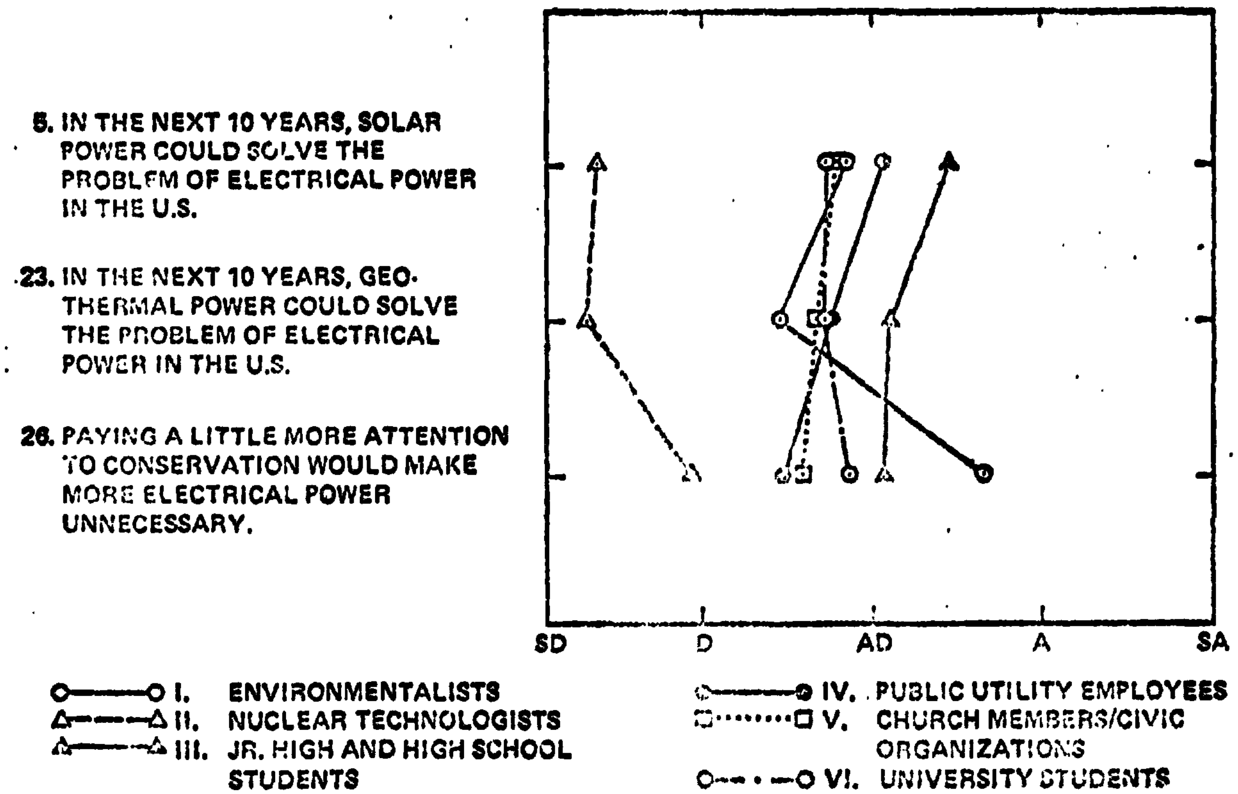


Figure 8.13

PERCEIVED EFFICACY OF ALTERNATIVES TO NUCLEAR POWER

Wood

year each received average judgments at the midpoint of the "satisfaction" scale or above. Fatality rates in excess of one death per year received average judgments which were closer to the very unsatisfactory end of the scale. Much the same findings were reported for the Long term safety factor. In general, however, at any given risk level, the risks were perceived as being more satisfactory as short term rather than long term risks.

The study also found that approximately 75% of the sample rated an increase of $3.00 in the monthly cost of electricity above the midpoint on the "satisfaction" scale. An increase of $10.00 was given an average satisfaction rating of just below the midpoint on the metric. The sample also felt than an accident detection and recovery system would be satisfactory only if it resulted in a death reduction of greater than 50% over no such system at all.

The different sub-groups had somewhat different ideas of what a satisfactory performance criteria should be. The extremes were occupied by the environmentalists and by the nuclear technicians. Their responses formed boundaries within which the remaining groups were contained. (Figures 8.5 to 8.8)

The investigators also asked a set of questions dealing with more generalized attitudes toward nuclear power and nuclear waste management. The average score for each of the groups on those items is shown in Figures 8.9 to 8.13. The marginal distributions of the questions is given in Table 8.1.

Attitudes Toward Nuclear Waste Disposal Factors

1. Who should bear the risks of nuclear wastes: Most groups were clustered around the middle of the agree-disagree scale except for nuclear

TABLE 8.1

ATTITUDE RESPONSE FREQUENCIES

FOR TOTAL SAMPLE

		SA	A	AD	D	SD
1.	Overpopulation and economic conditions are more serious threats to our way of life than the problem of nuclear waste disposal.	100 22%	151 33%	94 21%	94 21%	19 4%
2.	Nuclear wastes should be disposed of in such a way that no one will ever be able to recover them.	147 32%	124 27%	69 15%	94 21%	24 5%
3.	In dealing with nuclear wastes, cost should be of no concern	60 13%	96 21%	75 16%	182 40%	45 10%
4.	Based on information I got from this study, the hazards of nuclear wastes are less serious than I thought.	11 2%	73 16%	131 29%	146 32%	97 21%
5.	In the next 10 years, solar power could solve the problem of electrical power in the U.S.	22 5%	101 22%	127 28%	146 32%	61 14%
6.	The loss of even one life from nuclear waste is unacceptable.	34 7%	71 13%	76 17%	178 39%	99 22%
7.	The U.S. can maintain a strong economy without having nuclear power.	34 7%	58 13%	100 22%	157 34%	109 24%
8.	The construction of nuclear power plants should be slowed until an absolutely safe waste disposal system has been developed and thoroughly evaluated.	96 21%	147 32%	46 10%	118 26%	51 11%
9.	Nuclear waste is one of the most serious threats facing the world.	41 9%	102 22%	91 20%	153 38%	71 18%
10.	The radioactive hazards in nuclear power are no greater than the environmental hazards from coal-burning power plants.	33 7%	75 16%	90 20%	176 38%	84 18%
11.	Future generations must be <u>totally</u> safe from our nuclear waste.	105 23%	170 37%	82 18%	78 17%	23 5%
12.	In my opinion, the information contained in this study seriously underestimates the real risks of nuclear wastes.	38 8%	80 17%	151 33%	163 36%	26 6%

---

[1]SA = Strongly Agree; A = Agree; AD = Neither Agree nor Disagree; D = Disagree; SD = Strongly Disagree

		SA	A	AD	D	SD
13.	The benefits of nuclear power more than outweigh the hazards in nuclear waste storage and disposal.	56 12%	148 32%	92 20%	109 24%	53 12%
14.	Nuclear power is the most promising source of electrical power for the next 30 years.	79 17%	184 40%	106 23%	53 12%	36 8%
15.	Whatever disposal system is devised, there must be a way to detect leaks and recover the waste.	247 54%	164 36%	26 6%	16 3%	5 1%
16.	Before I got involved in this study, I knew very little about the problem of nuclear wastes.	55 12%	115 25%	56 12%	165 36%	67 15%
17.	The construction of additional electrical power plants will not be necessary for the U.S. to maintain its present standard of living.	15 3%	44 10%	80 17%	188 41%	131 29%
18.	I would not want to have nuclear wastes disposed of in my region of the country.	98 21%	115 25%	87 19%	121 26%	37 8%
19.	The generation that uses nuclear power should take all the risks for waste disposal.	52 11%	117 26%	78 17%	152 33%	59 13%
20.	Government and industry have done a good job of keeping the public informed about the advantages and disadvantages of nuclear power.	12 3%	42 9%	48 10%	194 42%	162 35%
21.	Based on past operating experience, nuclear energy has been demonstrated to be a clean and safe source of electrical power.	43 9%	173 38%	133 29%	81 18%	28 6%
22.	Participating in this study makes me realize just how frightening nuclear waste is.	31 7%	119 26%	110 24%	135 29%	63 14%
23.	In the next 10 years, geothermal power could solve the problem of electrical power in the U.S.	9 2%	58 13%	186 41%	130 28%	75 16%
24.	Using more coal is far less harmful to man than using nuclear power.	11 2%	80 17%	150 33%	164 36%	53 12%
25.	To satisfy critics, the U.S. nuclear waste system will probably cost far more than is necessary.	48 10%	178 39%	89 19%	100 22%	43 9%

		SA	A	AD	D	SD
26.	Paying a little more attention to conservation would make more electrical power unnecessary.	47 10%	97 21%	98 21%	169 37%	47 10%
27.	We should immediately stop developing nuclear technology as an energy source.	10 2%	22 5%	51 11%	179 39%	196 43%
28.	The main concern of nuclear waste planners should be a safe system for the short term.	25 5%	95 21%	68 15%	212 46%	58 13%
29.	Compared to other problems that future generations will face, nuclear waste monitoring is insignificant.	23 5%	50 11%	94 21%	192 42%	99 22%
30.	If the United States does not increase the production of electricity, our economy will decline.	66 14%	194 42%	116 25%	66 14%	16 3%

Source: BNWL-1997

technologists who clearly disagreed that the users of nuclear energy should bear the risks of waste management.

2. Absolute safety: Most groups agreed that the future should be 100% safe...except for the nuclear technologists who disagreed.

3. Significance of waste problems: Environmentalists and nuclear technicians bracketed the responses of the other groups on this question.

4. Concern about cost: Fair consensus around the middle of the agree-disagree scale that cost should be no object.

5. Irretrievability: Wide variance on this issue. Interestingly, the environmentalists and the nuclear technicians are closer on this issue than on any other...both tend to desire retrievability.

6. Detection and recovery: Strong consensus among all groups except nuclear technicians that leaks should be detected and remedied. There may be some logical inconsistency between the responses on this question and the responses on the previous item.

Perceived Severity of Nuclear Waste Problem

1. Relative to overpopulation and economic conditions: All groups except junior and senior high students and environmentalists place more concern on those problems than on nuclear waste management.

2. Loss of one life: All the groups, to varying degrees, disagree with the idea that even one life lost because of nuclear wastes is one life too many.

3. Serious threat: None of the groups agree that nuclear waste is one of the most serious threats; there is however, a wide range of opinion expressed.

Perceived Safety of Nuclear Power

1. Slow nuclear power until waste can be handled: An extraordinarily wide range of attitudes. Nuclear technologists and environmentalists mark off the boundaries with the remaining groups in between.

2. Nuclear vs. Coal: Only the nuclear technicians believe that the risks of nuclear power are less than coal fired plants.

3. Benefits of nuclear power: Most groups neither agree or disagree with the idea that the benefits of nuclear power outweigh the risks of waste management. Only the environmentalists and the nuclear technicians express strongly held views.

4. Disposal in the respondent's region: Only the nuclear technologists seem prepared to accept wastes disposed in their immediate environment.

Perceived Need for Nuclear Power and Need for Power in General

With only the environmentalists dissenting, there is a relatively strong consensus that nuclear power is required for a strong economy, that it is the most promising energy source for the next generation, that it is necessary for the maintenance of our present standard of living, and that its development must be continued.

Perceived Efficacy of Alternatives to Nuclear Power

With the exception of nuclear technologists who have no faith in the alternatives of solar, geothermal, or conservation, the remaining groups are by and large ambivalent about alternative sources of energy being practical in the near term.

Evaluation of the Study

The study appears to be competently, although not imaginatively, conducted. The investigators are to be complemented on trying to measure difficult value trade-offs in a number of different ways. The lack of breadth, both in devising the measures of systemic performance and in the range of issues considered is somewhat disappointing. More importantly, the study suffers from four limitations which combined out to make one cautious about how much weight is given to its findings:

a. Sample: Quota sampling makes sense if you wish to find out the opinions of particular groups of individuals. The disadvantage of that sampling design is that it is hard to generalize to any other population--particularly to a cross section of Americans. If we believe that the six groups isolated are the only ones whose voice does or ought to count the problem may not be a large one. But if we believe that waste management is an issue that touches virtually everyone, then perhaps we need to find out their attitudes as well. This study tells us nothing about that larger set of opinions.

b. Inference: A major technical failing of the study is the lack of information about confidence intervals around the mean scores. Differences in the means among the various groups may simply be due to sampling errors. This is particularly likely because of the small sample sizes employed. The study does not provide us with a way of determining whether the differences are "real" or are merely statistical artifacts.

c. Reliability and validity of the measures: By measuring the importance of the four factors in four ways, the investigators could assess the reliability and validity of their measures. Using the methods of ranking and the "thermometer" scale produced similar results--although the score from one method could only explain about 60% of the variation in the scores obtained from using the other method. The situation was worse when the measures of importance derived from regression coefficients were used to predict scores obtained from the other two methods. Less than 30% of the variation could be explained. Still worse was the use of the "minimally acceptable" method in explaining scores obtained using the other three methods. Here less than 10% of the variation in the three other scores could be explained. The last method, then, clearly measures something other than the importance attached to each of the four factors.

d. Explanatory power: The major limitation of the study was it failure to provide explanatory reasoning for its findings. Marginal distributions do not reveal much. They may be subject to measurement error or they may be highly unstable. If explanatory variables can be found which make theoretical sense, then the significance of the study increases by several orders of magnitude. We can view the variables measured--particularly the importance of the four factors and their associated acceptable levels of performance--as dependent variables located at the tip of the stem of a funnel of causality. The further back along that stem we can go in establishing causal and explanatory antecedents, the more we can understand the context of opinion and the richer the measurements become. In addition, secondary analysis would reveal inconsistencies and paradoxes which would further inform our understanding. The investigators have not undertaken any such explanatory or secondary analysis to date. Until they do we ought to be wary of attaching much significance to their findings.

A SURVEY OF PUBLIC AND LEADERSHIP ATTITUDES TOWARD NUCLEAR POWER DEVELOPMENT IN THE UNITED STATES: A Survey Conducted by Louis Harris and Associates for EBASCO Services Inc.; August 1975.

This survey was carried out in the spring of 1975. A national cross section of 1537 adults were interviewed in their homes. In addition, 301 persons who lived near nuclear power plants were interviewed. Finally fifty people from each of four leadership groups (political leaders, regulators, business leaders, and environmental leaders) were surveyed. The questionnaire dealt with a broad range of topics including the nature of the energy shortage, advantages and disadvantages of nuclear power, and the acceptability of nuclear plants in the respondent's community. I have selected out the data which bears directly on the question of nuclear waste management. (See Tables 8.2-8.6)

a. Open-ended responses: Those interviewed were asked what they perceived were the major disadvantages of nuclear power. This type of question provides information about what the respondent feels is important--not what the researcher deem significant or wishes to know. Responses from this type of question provide a good indicator of what the person believes is salient. Ten percent of the total public spontaneously mentioned waste disposal as a problem area. In terms of sheer numbers, waste disposal was the fifth most mentioned disadvantage. Among the leaders, however, waste management enjoyed a significantly higher degree of salience. It ranked first among environmentalists and regulators. Even among business and political leaders, waste management problems were mentioned quite frequently.

Table 8.2

TWO OR THREE MAIN DISADVANTAGES OF NUCLEAR POWER PLANTS

	Total Public %	Total Nucplant Neighbors %	Political Leaders %	Business Leaders %	Regulators %	Environmentalists %
Unsafe, dangerous	23	18	16	24	15	15
Danger of radiation contamination, leaks, cracks in reactor	20	23	41	25	30	37
Danger of accidents, explosions, earthquakes	14	21	4	14	15	27
Thermal pollution, kills marine life	12	23	14	10	21	12
Problems with radioactive waste disposal	10	9	37	22	34	50
Pollution, damage to environment	9	14	14	6	15	6
Expensive, high cost	7	6	43	24	23	19
Initial expense is high; financing problems	7	7	2	12	13	8
Lack of technical knowledge, uncertainty of consequences	6	6	10	12	15	13
Need stringent controls, safeguards	5	7	6	2	4	10
Public anxiety over safety; objections of environmental groups	4	10	16	22	15	4
Danger of sabotage	2	3	10	6	6	21
Sites not available	2	6	6	4	4	2
Danger to workers in nuclear plants	1	1	2	4	2	4
Puts people out of work	1	1	-	-	-	
Inefficient, breaks down	1	1	8	2	2	12
Shortage, lack of plutonium	1	2	10	8	9	6
Length of construction time	-	-	6	8	13	-
Fuel getting into wrong hands; theft of plutonium	-	-	4	2	4	10
Exempted by government from liability claims, insurance coverage	-	-	-	-	2	8
Human carelessness, error	-	-	2	-	-	-
All other answers	5	10	14	6	11	31
None, no disadvantages	9	12	-	8	2	-
No anwer	1	*	-	-	-	-
Don't know	27	14	-	-	-	-

Table 8.3

PROBLEMS CONNECTED WITH NUCLEAR POWER PLANTS

	Total Public %	Total Nucplant Neigh-bors %	Poli-tical Leaders %	Busi-ness Leaders %	Regu-lators %	Environ-mental-ists %
The disposal of radioactive waste materials which remain radioactive for many centuries to come						
Major problem	63	66	82	57	76	98
Minor problem	14	15	10	29	20	2
Hardly a problem at all	7	5	4	14	2	-
Not sure	16	14	4	-	2	-
The escape of radioactivity into the atmosphere						
Major problem	49	47	33	22	39	62
Minor problem	19	19	29	14	28	25
Hardly a problem at all	17	22	35	63	33	10
Not sure	15	12	3	1	-	3
The chance of an explosion in the case of an accident						
Major problem	47	45	14	18	17	45
Minor problem	28	25	37	29	43	29
Hardly a problem at all	13	20	47	51	37	20
Not sure	12	10	2	2	3	6
The discharge of warm water into lakes and rivers that would endanger fish and other water life						
Major problem	47	47	43	22	4[illegible]	58
Minor problem	28	27	45	51	40	38
Hardly a problem at all	13	18	10	27	16	2
Not sure	12	8	2	-	-	2
The threat of attempts to sabotage nuclear power plants						
Major problem	39	41	38	16	26	63
Minor problem	32	26	38	60	43	33
Hardly a problem at all	16	24	22	24	28	4
Not sure	13	9	2	-	3	-

Table 8.3 con't

PROBLEMS CONNECTED WITH NUCLEAR POWER PLANTS

	Total Public %	Total Nucplant Neighbors %	[illegible]i-[illegible]al Leaders %	Business Leaders %	Regulators %	Environmentalists %
Giving off fumes that can pollute the air						
Major problem	36	34	12	6	13	15
Minor problem	26	19	37	27	24	35
Hardly a problem at all	21	36	49	65	58	44
Not sure	17	11	2	2	5	6
The possibility that plutonium, which is made in a nuclear power plant, could be stolen by radical revolutionaries						
Major problem	34	34	48	20	33	77
Minor problem	29	21	28	47	47	19
Hardly a problem at all	18	28	24	33	20	4
Not sure	19	17	-	-	-	-

Table 3.4

"MAJOR" PROBLEMS CONNECTED WITH NUCLEAR POWER PLANTS

	Total Public %	East %	Mid-west %	South %	West %	Cities %	Sub-urbs %	Towns %	Rural %	18-29 %	30-49 %	50 and Over %	Some High School or Less %	High School Grad./Some Col-lege %	Col-lege Grad %	Building More Nuclear Power Plants in U.S. Favor %	Building More Nuclear Power Plants in U.S. Oppose %
The disposal of radio-active waste materials which remain radio-active for many cen-turies to come	63	67	67	55	62	64	65	58	63	72	62	56	53	67	72	58	86
The escape of radio-activity into the atmosphere	49	57	53	43	40	55	46	42	47	61	48	40	46	51	49	41	76
The chance of an ex-plosion in the case of an accident	47	55	45	47	36	50	45	40	49	51	48	43	51	46	38	36	70
The discharge of warm water into lakes and rivers that could en-danger fish and other water life	47	49	52	41	42	53	43	44	45	50	45	45	45	46	53	40	72
The threat of attempts to sabotage nuclear power plants	39	42	39	38	37	42	33	41	38	38	40	40	44	38	32	35	53
Giving off fumes that can pollute the air	36	42	34	36	30	43	31	33	35	47	33	31	39	36	27	27	61
The possibility that plutonium, which is made in a nuclear power plant, could be stolen by radi-cal revolutionaries	34	38	33	30	35	38	33	33	30	36	35	32	34	35	31	31	49

Table 8.5

NEGATIVE STATEMENTS ABOUT NUCLEAR POWER PLANTS

	Total Public %	Total Nucplant Neighbors %	Political Leaders %	Business Leaders %	Regulators %	Environmentalists %
A major radiation leakage from a nuclear power plant can cause fall-out that can kill large numbers of people						
Completely true	35	46	29	22	32	71
Partly true	27	21	27	22	30	21
Partly untrue	6	8	16	18	26	6
Completely untrue	6	8	22	33	9	2
Not sure	25	17	6	5	3	-
Hot water from nuclear power plants endangers fish and other water life in nearby lakes and streams						
Completely true	33	44	35	20	35	50
Partly true	33	24	49	39	54	48
Partly untrue	5	8	8	20	7	2
Completely untrue	5	11	8	18	2	-
Not sure	24	13	-	3	2	-
Waste from nuclear power plants can cause radioactivity exposure to too many people						
Completely true	25	32	26	16	26	67
Partly true	29	21	36	8	28	25
Partly untrue	11	10	24	20	19	2
Completely untrue	9	15	14	51	23	4
Not sure	26	22	-	5	4	2
If nuclear power were being produced all over the country, some revolutionaries or criminals could steal nuclear materials and make their own atom bombs						
Completely true	21	24	28	10	15	60
Partly true	34	26	36	31	43	31
Partly untrue	11	12	12	24	21	4
Completely untrue	13	23	24	29	17	2
Not sure	21	15	-	6	4	3
A nuclear power plant can fail and the nuclear materials can come together to cause a massive nuclear explosion						
Completely true	17	23	6	6	[illegible]	21
Partly true	22	19	12	12	17	12
Partly untrue	9	7	16	2	9	8
Completely untrue	15	21	59	55	53	52
Not sure	37	30	7	25	12	7

Table 8.6

RISKS WORTH TAKING

	Total Public %	Total Nucplant Neighbors %	Political Leaders %	Business Leaders %	Regulators %	Environmentalists %
Allowing people to use natural gas in their homes, if precautions are required to make sure leakage will not asphyxiate people or cause an explosion	85	88	96	94	98	100
Allowing automobiles to be sold, if the federal government checks up on how safe they are and requires manufacturers to call back defective cars to be fixed	85	87	98	100	98	92
Allowing coal to be mined deep in the ground, if the mine is inspected to be sure miners will be safe from a cave-in	83	79	98	93	96	94
Allowing people to use sleeping pills, pep pills, and tranquilizers, if they can be obtained only through a doctor who explains the dangers of misuse	80	7[illegible]	94	96	94	90
* Allowing nuclear power plants to be built, if the government certifies that they will not pollute the air and water	80	81	73	94	85	27
* Allowing nuclear power plants to be built, if the government regularly inspects the plant to be sure there is no radioactive leakage	79	77	70	92	85	29
* Allowing nuclear power plants to be built, if the plants meet tough government standards for nuclear waste disposal	79	80	74	94	87	27
* Allowing nuclear power plants to be built, if the plants are prohibited from dumping warm water into streams and lakes that could endanger fish and other water life	76	71	84	92	87	33
* Allowing nuclear power plants to be built, if the government is satisfied on inspection that an accidental explosion is unlikely to happen	75	77	66	90	81	21

(continued)

Table 8.6 con't

RISKS WORTH TAKING

	Total Public %	Total Nucplant Neighbors %	Political Leaders %	Business Leaders %	Regulators %	Environmentalists %
Allowing nuclear power plants to be built, if the plants have proper security to prevent the stealing of plutonium or the sabotage of the plants by revolutionaries	75	75	78	94	85	29
Allowing liquor to be sold to adults, if the public is warned about the dangers of alcoholism	[illegible]	78	94	94	91	92
Allowing cigarettes to be sold, if the packages have a clear warning of the dangers of cigarette smoking	68	77	86	90	83	87
Allowing strip mining for coal to tear up the ground surface, if the coal producer is required to reclaim the land after using it	68	71	90	92	91	75
Allowing prescribed drugs that can kill people from overdose to be sold, if the package warns people about the dangers of excessive use	62	66	96	80	85	87
Allowing synthetic fabrics to be sold for clothes, curtains and rugs, if people are warned of the dangers of such fabrics catching fire	55	51	45	69	57	50

b. Close-ended questions: The sample was then asked specifically how much of a problem they perceived waste management to be. When confronted with the issue, over sixty percent of the public felt it was a major problem and another fourteen percent felt it was a minor problem. Political leaders, regulators, and environmentalists recognized the potential problems in waste management by majorities ranging from 76% to 98%. In sharp contrast, only 57% of the business leaders felt that waste disposal was a major problem.

c. Demographic and attitudinal correlates of opinion: The attitudes of the public about waste management were not evenly distributed across demographic lines. People living in the South and/or in small towns, those age fifty and over, and those with less than high school education tended to see less of a problem. Not surprisingly, those opposed to nuclear power tended to see more of a problem in waste disposal than those who favored the nuclear option.

d. Radioactive releases from waste: Over one half of the public found some truth in the claim that wastes can cause radioactivity exposure to too many people. Only one quarter of the business leaders felt that the statement was truthful while over ninty percent of the environmentalists were convinced of its correctness.

e. Risks worth taking: By margins ranging from 74% to 94% all the groups interviewed except for environmentalists felt that nuclear power plants should be allowed to be built if tough standards for nuclear waste disposal could be enforced. The environmentalists demurred; only one quarter of them were willing to see society take such a risk.

Evaluation

This study does not suffer from some of the weaknesses of the first one. It uses a cross section sample of sufficient size that virtually all the differences noted are likely to be significant. This study fails, in general, to provide any explanation of the attitudes measured; thus, we are somewhat at a loss to interprete them sensibly. Because of the study's broader nature, little or no attention was paid to measurement reliability and validity.

Implications of the Data for Understanding Public Attitudes Towards the Space Disposal Option

The EBASCO study provides the context for understanding how the public relates the issue of waste management to other nuclear issues and to other types of social risks. To the extent that the public sees the problem as pressing the chances of devoting significant social resources to its solution are increased. This is particularly important for the space option as its cost will most likely be greater than virtually all other alternatives.

Waste management was not viewed as a very important problem by the general public in the open ended questions (Table 8.2). More immediate issues tended to dominate public concern such as radioaction leakages and thermal pollution. However, among regulators and political leaders who shape policy alternatives the question of waste management was extremely salient. It would seem then that the space option would not be eliminated as a possible method of waste disposal simply on the basis of its cost if it came to be seen as the only viable method. The data does not provide any insight on what choices would be made if several possible methods, among them the space option, were in competition.

The data in Table 8.3 casts the problem of waste management in more pleasing of a light than the data considered above. Here the problem of waste disposal is viewed as more severe than radioactive releases to the atmosphere, the chances of explosion, thermal pollution, sabotage, air pollution, or safeguards. Again the attitudes of key governmental leaders are stronger than those of the public in general. These attitudes suggest a strong commitment to finding some solution to the problem of waste disposal. The space alternative could profit from that commitment if insurmountable difficulties--whether technological or political--begin to plague other alternatives.

The Battelle study provides the basis for assessing public reactions to the space option compared to other possible alternatives for waste management. The space option is characterized by the fact that it tends to increase short term risks of management because it requires a greater number of steps in handling and storage and because it introduces an additional risk of booster failure; the alternative does, however, reduce long term risks, almost to zero, once the rocket has left the earth; the space option is also distinguished by the fact that accidents are highly visible--detection, if not rectification, is not a major problem; finally, the space option tends to be more costly than other alternatives such as burial in salt or in the seabed.

Those four characteristics which distinguish the space disposal option from other alternatives were precisely the four factors which the Battelle group studied. Significantly, cost considerations, which many observers cite as a major reason why the space option would not be viable, was the least important value for every group surveyed. (Figures 8.2 to 8.4) For five out of the six groups, cost considerations were far less important than any of the other three evaluative criteria. Even among nuclear technologists, the sixth group, cost was the least important factor in assessing a system, although not as by great a margin as with the other groups.

In addition, the prime virtue of the space alternative, the complete removal of the material so that the long term risk is reduced to zero, was considered to be of prime importance by all of the groups polled except the nuclear technologists. They all considered the reduction of long term risk the single most important dimension along which a waste mangement system was to be evaluated.

Countering those trends which were clearly supportive of the idea of space disposal were the responses dealing with short term safety and with accident detection and recovery. Avoidance of short term risks was considered highly important by all the groups polled. In fact, depending on which measure is used, some groups valued reduction of short term risks more highly than reduction of long term risks. Similarly, accident detection and recovery ranked fairly high as a criteria for choice...although it was generally not as important as either the reduction of long term or short term risks. Since the space disposal option will probably increase the short term risks and will make accident recovery (although not detection) more difficult, the data suggests that a positive attitude resulting from the space option's favorable position of reducing long term risks may very well be completely reversed when the total range of values is included. We have, of course, no way of knowing for sure just how the four values will be aggregated by the public as it makes its evaluations. But the data certainly does not suggest that the space option will be met by enthusiasti public response even in the abstract.

Notes to Chapter 8

1. "Public Values Associated With Nuclear Waste Disposal," Report BNWL-1997, Human Affairs Research Centers, Battelle Memorial Institute, Seattle, Washington, June 1976.
2. "A Survey of Public and Leadership Attitudes Toward Nuclear Power Development in the United States" a survey conducted by Louis Harris and Associates for EBASCO Services, Inc.; August 1975.