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INSTITUTE FOR ENERGY AND
ENVIRONMENTAL RESEARCH

Washington, D.C. office:
6935 Laurel Avenue
Takoma Park, MD 20912
U.S.A.
Phone: (301) 270-5500
Telex: 6502975485

REDUCING THE RISKS:

POLICIES FOR THE MANAGEMENT OF HIGHLY RADIOACTIVE NUCLEAR WASTE

by

Arjun Makhijani, Ph.D.

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European office: IFEU – Institut für Energie-und Umweltforschung Heidelberg e.V., Im Sand 5, 6900 Heidelberg, Federal Republic of Germany, Tel 011-49) 622[illegible]

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A SYNTHESIS

Preface

The long-term management of nuclear wastes is a difficult and vexing technical, environmental, economic and political issue. The wastes are dangerous, and the danger will persist for millennia.

After two decades of general and site specific research, the technical problems of siting and developing permanent nuclear waste disposal sites that would protect the environment and the health of present and future generations are far from resolution. The problems with the federal government's waste disposal program prompted thousands of citizens in more than a dozen states to become directly involved in opposing the program. The purpose of this report is to summarize the technical issues, the history of the program, alternative waste management strategies, and to suggest a long-term waste management program in order to provide a framework for the needed national reexamination by citizens, scientists, and Congress of the nuclear waste program and current federal policy. This study is based on documents and status of the work as of the end of 1988.

Part I discusses the current approach and the problems it has encountered. Part II is a review of the alternatives available for long-term management, of interim management options, and of associated issues such as reprocessing of spent fuel. A plan is recommended in Part III. This includes both technical aspects and recommendations regarding the institutional arrangements which might work better than the present ones.

All measurement units are metric, unless otherwise specified.

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Arjun Makhijani
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CHAPTER 1

SUMMARY AND RECOMMENDATIONS

The selection of the Yucca Mountain site in Nevada as the only site for study by way of the 1987 amendment to the Nuclear Waste Policy Act of 1982 was the last in a series of steps based on poor science, technically indefensible standards, some of which have been thrown out by the courts, and political expediency. It was based on a sense of urgency about building a repository, which is not borne out by a careful examination of the problem. It is a risky course, which might further erode public confidence in the government's ability to manage this problem with integrity, and which might result in further long delays and misdirected large expenditures.

From a technical standpoint, the program has proceeded in reverse from its beginnings. A technically sound program would define the health and environmental objectives first, and then try to study the various ways in which the objective might be attained. It would also recognize the enormous uncertainties faced by this unique enterprise, and attempt to address them.

Instead, an early hunch that salt would be a satisfactory geologic medium for burying wastes, performing to unspecified standards of containment and public health protection, was allowed to monopolize about two decades of effort, littered with embarrassing failures, notably at Lyons, Kansas in the early 1970s.

The 1982 Nuclear Waste Policy Act did not allow enough time for reasonable standards to be developed and debated. Under such circumstances, political expediency prevailed, which has only caused more delays. The Department of Energy (DOE) already had many sites under consideration either in salt or on Federal land. The Nuclear Regulatory Commission (NRC) had already published draft technical standards for repository performance. But the health and environmental standards to which both the DOE site selection and the NRC technical standards would have to conform had not yet been finalized. The draft Environmental Protection Agency (EPA) standards were published in 1982; they were finalized in 1985; they were invalidated by the courts in 1987.

This situation arose in part because the Environmental Protection Agency also took a course of political expediency (along with the DOE and the NRC). It adopted the attitude that it would promulgate standards which would relate not to minimizing radiation doses to individuals but rather to its own incomplete and flawed assessment of how well a repository would perform. The Waste Isolation Systems Panel of the National Academy of Sciences (referred to in the rest of this report as the National Academy Panel) had already published in 1983 an extensive critique of the draft EPA standard:

> "...[T]he proposed standard is considered by the EPA staff to be 'technology-based, not risk based'...and the standard represents EPA's best estimates of how well a repository can be expected to perform without necessarily considering the risks that may develop from the releases."[1]

The 1983 National Academy study found that the proposed EPA standard was compatible with doses so miniscule that they could hardly be measured (tiny fractions of a rem per year) and so large that they would be lethal (10,000 rem per year). Yet, the EPA went ahead and finalized the standard in 1985. It was rejected by the courts in 1987 as being out of compliance with other health and environmental laws.

As a result, today there are no legal health and environmental standards which govern the process of site selection, characterization, and licensing. In spite of this, the NRC has finalized its standards for repository performance which are supposed to meet criteria for the protection of public health and the environment which do not yet exist. It seems unlikely that, under the current circumstances, the EPA will propose standards which would require the NRC to sericusly reformulate its final regulations.

The NRC appears to be endorsing this Alice-in Wonderland approach, whereby technical regulations have been finalized and repository selection and design are proceeding without any legal health and environmental standards. In its comments on the Nevada site characterization efforts it noted that "it is our understanding that DOE prepared the CDSCP [Consultation Draft Site Characterization Plan] on the vacated [EPA] standard." It went on to say that the "NRC considers this approach reasonable" and that only "departures from this standard need to be examined by the DOE."[2] The NRC does not explain why it is "reasonable" to proceed on the basis of a fundamentally flawed standard which has been invalidated by the courts.

The selection of the Nevada site as the most promising on technical grounds was based on faulty reasoning which ignored both internal DOE scientific work, and calculations published years earlier by the National Academy Panel.

The principal presumed advantage of the Yucca Mountain site relates to the plan to locate the repository above the water table. With low rainfall and the additional assumption that this would persist for tens of thousands of years, the outlook for waste containment was presumed to be very promising. In addition, it was thought that the little water from rain and melting snow that does percolate through the proposed repository site could be channeled around the waste, keeping the waste out of contact with water. A repository that accomplished this promised successful isolation of radioactive wastes from the human environment, since water is generally presumed to be the principal means of transport of radioactive materials out of the repository.

But an internal 1987 DOE report, dated November 1987, one month before the 1987 amendment to the 1982 Act which mandated restricting site characterization to Nevada, raised the possibility that geological changes well within the period for which the waste would remain dangerous could saturate the repository with water. DOE ignored or suppressed the report. It became public only after the passage of the Act.

This is but one example in a long and consistent history in which DOE has ignored, brushed aside, denigrated or suppressed important information and analyses which pointed to essential problems with any site that it chose to study. It ignored information which pointed to grave defects of the Lyons Kansas site, until it became an embarrassment. It did the same with Hanford, Washington, despite repeated attempts by the National Academy Panel and others to call attention to the problem of high rock stresses there.

Its Draft Area Recommendation Report of January 1986 for sites in the East, South and Midwest, which was three years in the making, ignored most of the relevant published literature, including special studies done by other governmental agencies at the direction of Congress to assist DOE. Indeed, it systematically, and for the flimsiest of reasons, ignored the most promising geologic formations in granite recommended by both the U.S. Geological Survey and by the National Academy Panel.

There is now evidence that DOE is also structuring the investigation of the Nevada site so that critical problems will be downplayed or not discovered. Yet, a 1983 National Academy of Sciences study had already warned that it was quite possible that a repository at Nevada might result in doses to individuals on the order of 1 rem per year -- which is 40 times higher than present standards allow from the operation of the entire nuclear fuel cycle.

DOE's performance so far points rather clearly towards an institutionalization of ignorance about those aspects of site selection and characterization which might reveal that any site which DOE chooses to study might wind up being a poor choice. This institutionalization does not appear to have been the product of any consistent decision-making process. It is probably merely the result of making environmental concerns secondary to the goals of promoting nuclear power and continuing nuclear weapons production. This has been revealed by a series of difficulties in other arenas of DOE's operations as well, especially the major nuclear weapons facilities.

The present course is based on an assumption that it was urgent to get the spent fuel off the reactor sites and bury it in a repository. Nuclear utilities, power plant manufacturers, many environmental groups, and arms control groups supported that idea in the early eighties for diverse reasons.

For the utilities and manufacturers the passage of a 1976 California law brought the issue to a head: no more nuclear power plants could be built until the problem of management of spent fuel or high-level nuclear wastes was satisfactorily resolved. Utilities were also concerned about the diminishing storage capacity for spent fuel in the pools at the reactor sites.

The environmental and arms control communities appeared to believe that a law requiring repository construction would mean that reprocessing would cease to be an option. Since reprocessing is a costly, polluting technology, posing serious risks for weapons proliferation, this appeared to lend some urgency to achieving some kind of solution which would foreclose reprocessing.

Now, after six years of problems, botched studies and technically shoddy work, the urgency has faded, in fact. The DOE will not accept spent fuel from nuclear utilities until 2003 at the earliest. This means that most of them will have to build additional capacity for storing fuel on-site.

The urgency with which the legislation and its amendment were passed has not precluded reprocessing. Many factors will contribute to the building up of stocks of spent fuel which could be reprocessed if sufficient social and political agreement to do so comes to exist at any time in the next several decades. Among them are: the much-delayed schedule; the risks of further serious delays; the possibility that the Federal government will build a Monitored Retrievable Storage at which much of the spent fuel in the country would be collected; and the Nuclear Regulatory Commission's requirement that the spent fuel be retrievable for fifty years after the opening of a repository, to reduce uncertainty.

Another aspect of this misplaced urgency has been that the entire operating money for site characterization so far has come from the ratepayers of electric utilities which own civilian nuclear power plants. Even though a decision has been made to put both military and civilian wastes in a single repository, an approach that would fairly apportion the costs being incurred today from such a commingling of wastes has not yet been worked out.

A. RECOMMENDATIONS

The dangers and costs of storing spent nuclear fuel at reactor sites appear to have been substantially reduced by the testing under NRC license of dry-cask storage. This method reduces considerably many of the environmental, economic, and accident risks posed by spent fuel storage in pools.

Extended on-site storage for up to 100 years will allow four of the most dangerous radionuclides which are also present in the largest quantities to decay substantially: krypton-85 (half-life, 10.7 years), strontium-90 (half-life, 28.8 years), cesium-137 (half-life, 30.2 years) and plutonium-241 (half-life 14.4 years). In doing so it will:

- o dramatically reduce transportation risks in case of serious accidents and radionuclide release;
- o make deferring the dismantling of nuclear power plants more economically attractive, enabling large savings in decommissioning costs, and reducing greatly the problems of low-level waste management;
- o allow time for the development and testing of safer transportation casks;
- o allow time for R&D on repository selection, design and construction.

- o enable a greater quantity of radioactive waste to be accommodated in a given repository volume because the waste will be considerably cooler.

Perhaps the preeminent reason in favor of on-site storage of spent fuel for an extended period (roughly 100 years) is that it would allow short- and intermediate-term goals to be made compatible with the goal of long-term isolation of wastes to a sufficient degree to prevent significant harm to the environment and to future generations.

It is also urgent that the serious near-term risks posed by the radioactive and other hazardous wastes at nuclear weapons production sites be reduced by an interim program, which would allow sound long-term options to be studied and developed. The length of time required to do the relevant research and to locate and build a repository is likely to be very long. The problems of pollution and of the risk of serious accidents at the nuclear weapons sites cannot wait for a repository to be available. At the same time, interim solutions must be robust enough that they will be able to accommodate a wide variety of repository locations and environmental criteria for long-term disposal.

Long-term management of highly radioactive wastes is a difficult enough problem, without the kinds of mismanagement with which DOE has saddled it. It is urgent that the program be pursued with scientific integrity, putting health and environmental considerations first, and clearly above political convenience.

It is also important to note that while large resources being devoted to a program of site characterization in Nevada, which has a substantial risk of failure, the urgent problem of solidifying the liquid high-level wastes weapons production at Hanford is proceeding too slowly. Past leaks and mismanagement have already caused a half a million gallons of this waste to contaminate the site. Liquid waste needs to be put into solid form as soon as possible to stop further site contamination and further increases in the already gigantic costs of containing the problems of pollution at the nuclear weapons sites.

The thrust of our conclusions is that the present EPA and NRC standards should be definitively discarded, and that the DOE should be removed from the process. An approach to public health protection recommended in 1983 by the National Academy Panel on waste isolation should be adopted. As for waste isolation criteria, equal emphasis should be placed on the cask and engineered barriers as on the geologic isolation.

A spent fuel canister with a much longer design life, would help reduce the present primary reliance on geologic isolation. This would considerably reduce the uncertainties associated with prediction of the performance of the geologic medium itself. The Swedish approach to long-term waste management puts considerably more reliance on the performance of the waste canister as an isolation mechanism that the U.S. approach. As an ad hoc National Academy of Sciences Panel noted in 1984:

> "The Swedish plan differs from most others in its heavy reliance on engineered barriers, specifically thick-walled copper canisters to enclose the spent fuel rods, surrounded by buffers of compacted bentonite."[3]

The Swedish estimate for isolation which would be achieved by the specially designed canisters, made by the Swedish Corrosion Institute, was on the order of 1 million years. The National Academy review concluded that this estimate was "fully justified."[4]

The National Academy review also concluded that if the estimate of isolation achieved by the canister plus the bentonite overpack for at least 1 million years is sound, then "the other parts of the [Swedish] disposal plan are of secondary importance."[5]

Taking this approach could be vital to the success of geologic isolation, even if a particular geologic setting appears to provide for adequate isolation. Among the changes that are difficult to predict, indeed at present they are impossible to predict with confidence, are the local effects of global climatic change. These could be severe, even if global average temperature changes are relatively small. This adds an element of uncertainty to any geologic setting, and reinforces the need to reject the present NRC standards for waste package performance.

Our principal technical recommendations for this program are:

1. The National Academy standard of maximum allowable dose to the individual from repository operation, over all time should be adopted. The Academy suggested a lifetime average of 10 millirem per year as the numerical figure. We believe that this should be lowered to take into account health risk to pregnant women and fetuses.

2. The waste canister and geologic performance should be given equal emphasis. Specifically, the NRC performance standards for waste package performance, which require containment of the wastes within the package for only 300 to 1,000 years should be scrapped. In their place, the Swedish approach to using the canister and overpack surrounding it as the primary containment for a million years or more should be adopted and improved.

3. Spent fuel should be stored on site using dry casks, or a comparable dry storage method which does not require forced ventilation. The potential complementarity of this with reactor decommissioning and low-level waste management should be carefully studied.

4. All site selection and site characterization work should be stopped. An intensive program of research on geology, including research in the basic science and all relevant sub-disciplines, should be initiated.

5. Solidification of high-level liquid wastes from nuclear weapons production should be given a very high priority.

6. Health, safety, and environmental issues at the nuclear weapons sites should be brought under the purview of local, state, and federal regulations and the corresponding enforcing agencies, which are applicable to civilian

facilities. This should include the interim management of high-level wastes from weapons plants.

7. Transportation risks should be reduced substantially by appropriate cask design, extended on-site storage, proper routing, etc.

8. Priority should be given to safe interim management of radioactive wastes at the nuclear weapons sites, for example by converting them into forms which do not pose dangers of catastrophic accidents or contamination of aquifers.

9. Collaborative efforts between countries should be undertaken, so that the program will be informed by the widest experience and the best available science.

Our recommendation that waste packages with predicted isolation capabilities of a million years or more be developed is all the more important if we recognize that natural and human-induced climatic change could be considerable in the next few hundred years. At present it appears to be beyond the capabilities of models to predict local effects of global climatic change with any confidence. This is likely to remain difficult for a considerable period. The study of climate, which is also crucial in other areas of environmental protection, is very important in the isolation of nuclear wastes. Research in the area of local effects of global change should be supported, in part, from funds allocated to long-term nuclear waste management.

Spent fuel storage on site will have to be licensed by the NRC. The rest of the program recommended above is essentially a research and development program for long-term management. This research and development program can be best managed by an appropriately constituted government agency. The work itself would be carried out by universities, governmental laboratories, and industry.

The most technically sound program is likely to fail if the management is not dedicated to technical and scientific integrity and to a democratic process, which can actively take into account and incorporate adverse facts and comments into its decision-making structure. The DOE, as an institution, lacks the history and the prerequisites for this job.

The DOE and its predecessor agency, the Atomic Energy Commission (AEC) have operated in secret, isolated from democratic oversight, regulating themselves even as they promoted nuclear weapons and nuclear power production. Self-regulation and secrecy have created a sorry environmental record, and a frequent inability to conduct scientific enquiry regarding sensitive subjects with integrity and openness. This has generally been the case with the search for a repository for civilian and military radioactive wastes.

In view of these conclusions regarding the DOE, perhaps the most important recommendation of this study is that the DOE should be removed from the search for a repository, including the research and development program that we recommend.

As regards the interim program of on-site storage for spent fuel, this comes under the jurisdiction of the Nuclear Regulatory Commission, in any case, and the DOE should have no role it. The interim management of high-level wastes at the nuclear weapons sites needs to be brought under civilian regulation, as recommended above.

There are many options for managing the long-term aspects of the program recommended above. We mention some examples which need careful examination. For instance, a special new division of the National Science Foundation could be set up to oversee the process. Or a new government agency, with its Board of Directors selected from among appropriate federal agencies, such as the EPA, NRC, DOE, Occupational Health and Safety Administration, the U.S. Geological Survey, etc,. could oversee this process. This approach would have the advantage that it would allow for direct, though necessarily limited representation from states and Indian tribes. Whether this is desirable in a program that would be focussed on research and development and whose mandate would exclude site selection (all possible geological formations would be carefully studied) is a matter for further debate.

Whatever the specific form, a clear accountability for progress in research, and in the expenditure of ratepayers' and taxpayers' funds needs to be integral to the management structure from the outset. Long before the program's present disarray, the National Association of Regulatory Utility Commissioners stated in Congressional testimony that the DOE effort "is not being based on cost-effective decision-making"[6] and thus the electric ratepayer's concerns were not being adequately taken into account in program design.

Management accountability, timelines, and cost effectiveness from a long-term perspective which includes health considerations, are evidently necessary in the development and testing of casks along the Swedish concept. It is also necessary in the research aspects fo the program which will be oriented towards geology and other basic science question. This is because in a long and complex research program it will be easy to lose sight of the ultimate goal of safely disposing off the radioactive wastes unless such accountability and evaluation is built into the program and management structure from the beginning. **The involvement of the regulators of nuclear utilities and through them the ratepaying public is therefore critical to a process which will have financial integrity built into it.**

Finally, the question of how costs will be apportioned between disposal of high-level military waste and civilian waste needs to be decided equitably so that nuclear utility ratepayers do not wind up subsidizing nuclear weapons production, whose costs are an issue fore the entire country.

PART I

THE CURRENT APPROACH

CHAPTER 2

CHARACTERISTICS OF HIGH-LEVEL RADIOACTIVE WASTE AND SPENT FUEL

Radioactive waste is generated in a variety of ways. By far the largest quantities of it are generated from the operations of nuclear power reactors, from the production of nuclear weapons, and from associated activities such as uranium mining and processing. This waste has been classified into several categories for regulatory purposes.

The nuclear fuel cycle begins with uranium mining. The wastes from mining and initial processing contain some uranium and its radioactive decay products. Of these, radium and its decay product radon (a gas) are of the greatest concern from the point of view of health and environmental protection. These wastes are known as "mill-tailings".

Uranium enrichment is a process of increasing the concentration of the fissionable isotope of uranium, U-235, relative to the non-fissionable isotope, U-238. This process also produces radioactive wastes. The uranium is pelletized and put into long fuel rods. Bundles of these fuel rods are loaded into nuclear power reactors. The uranium for the reactors which produce plutonium for nuclear weapons has a different mix of U-238 and U-235 than nuclear power reactors.

When uranium is irradiated with neutrons in nuclear power reactors, U-235 fissions to yield energy and radioactive fragments called fission products. Neutron irradiation of U-238 produces, among other things, plutonium-239, the isotope used to make nuclear weapons.

Nuclear reactions slow down considerably once a certain quantity of fission products has accumulated in the fuel rods. As a result, fuel rods are withdrawn from power reactors before all the U-235 is consumed. Irradiated fuel rods, known as "spent fuel", are highly radioactive and very hot (thermally). The bulk of the radioactivity slated for the disposal in repositories under the Nuclear Waste Policy Act consists of the spent fuel.

It should be noted here that spent fuel from power reactors can be processed chemically to recover uranium and plutonium. This is known as reprocessing.

While reprocessing is not essential to nuclear power, it is essential to producing plutonium for nuclear weapons. After U-238 is converted to plutonium in nuclear reactors, the fuel rods contain uranium, fission products, various isotopes of plutonium, and other "transuranic" elements -- that is elements with atomic numbers higher than uranium (which has atomic number 92) in the periodic table of elements.

Reprocessing is used to recover the plutonium for making nuclear weapons. The liquid wastes fr reprocessing are highly radioactive and very hot. They are known as "high-level" radioactive waste by the Nuclear Waste Policy Act. Any further processing of these wastes which yields products which contain "sufficient concentrations" of radioactivity are also defined as "high-level radioactive waste" by the Nuclear Waste Policy Act of 1982.[7]

There are two other categories of waste:

1. Transuranic waste, which contains primarily transuranic elements or their compounds in sufficient concentrations. These result primarily from nuclear weapons production;

2. "Low-level" radioactive waste. This is a catch-all category for wastes that do not fit into any of the other categories and consists of wastes in relatively dilute form. Note that the total quantity of radioactivity in 'low-level' waste may be quite large, and often is. These wastes are generated in a large number of ways, including research and medical applications, but the bulk of them come from nuclear power and nuclear weapons production.

Considerable wastes will also be generated by the decommissioning of nuclear power and weapons plants and associated facilities. At present, the plans are to classif them into one of the above categories for the purposes of disposal.

Generally, the long-term management of mill tailings, low-level wastes, transuranic wastes, high-level waste, and spent fuel have been considered as separate issues, with separate solutions.

Current plans call for the disposal of low-level wastes at various state-owned sites around the country, some of transuranic wastes (about 20%) in a repository near Carlsbad, New Mexico (The Waste Isolation Pilot Plant known by its acronym WIPP), and spent fuel and high-level radioactive waste in a geologic repository, somewhere in the country. The Yucca Mountain site in Nevada, which borders on the Nevada Test Site for nuclear weapons testing, was designated by Congress in 1987 as the only candidate site for investigation at present. Mill tailings are generally being dealt with on-site or near the site, on an ad hoc basis. Considerable problems remain to be addressed in each of these areas. We will deal with spent fuel and high-level radioactive wastes in this report. We will also address those areas in which these problems might have significant overlap with other areas of nuclear waste management.

A. SPENT FUEL

When the chain reaction in a reactor stops, the fuel is intensely hot. In addition, heat continues to be generated by the radioactive decay of fission products. These fission products have half-lives that range from a fraction of a second to millions of years. The ones that decay most rapidly generate the most heat at first, being the principal source of heat in cases of melt-down accidents, such as the one that occurred at Three Mile Island.

After removal from the reactor, the fuel is so hot that it must be stored underwater for a considerable period, with the water circulating constantly. However, the presence of water tends to promote chain reactions. Water is a "moderator"; it slows down neutrons. Slow neutrons can fission U-235. As a result, the water is laced with boron which absorbs neutrons and prevents an accidental criticality (self-sustaining nuclear reaction).

The spent fuel is stored in pools at the reactor sites, which have pumps for circulating borated water. The radioactivity and heat production decays rapidly at first and then more slowly. The characteristics of spent fuel from pressurized water reactors (the most common type) and boiling water reactors are similar, but not exactly the same.

Figure 1a shows that radioactivity in spent fuel which initially contained one metric ton (MT) of uranium (known as "heavy metal" and abbreviated as HM) for pressurized water reactors (PWRs). The radioactivity depends on the extent of irradiation of the fuel because that is the determinant of the quantity of fission products in the spent fuel. Irradiation is measured by the amount of heat generated by the fission reactions (in units of megawatt-days or MWd).

One year after withdrawal from the reactor, the radioactivity in a ton of heavy metal irradiated for 25,000 megawatt-days is almost 2 million curies. In ten years this is down to about 300,000 curies. In a hundred years, it is about 30,000 curies.

The heat generation follows the radioactivity. It goes down from about 7,000 watts per ton of heavy metal after 1 year to about 1,000 watts after ten years and 200 watts after 100 years. This is shown in Figure 1b.

Figures 2a and 2b show the graphs of radioactivity and heat generation for spent fuel from boiling water reactors.

Different radionuclides are important at different times. The short half-life fission products, like iodine-131 (half-life, eight days), dominate the health threats early on. Other elements, like ruthenium-106 become relatively more important at intermediate times (on the order of 1 year). For intervals over a few years, three kinds of radioactive isotopes are important:

PRESSURIZED WATER REACTOR SPENT FUEL

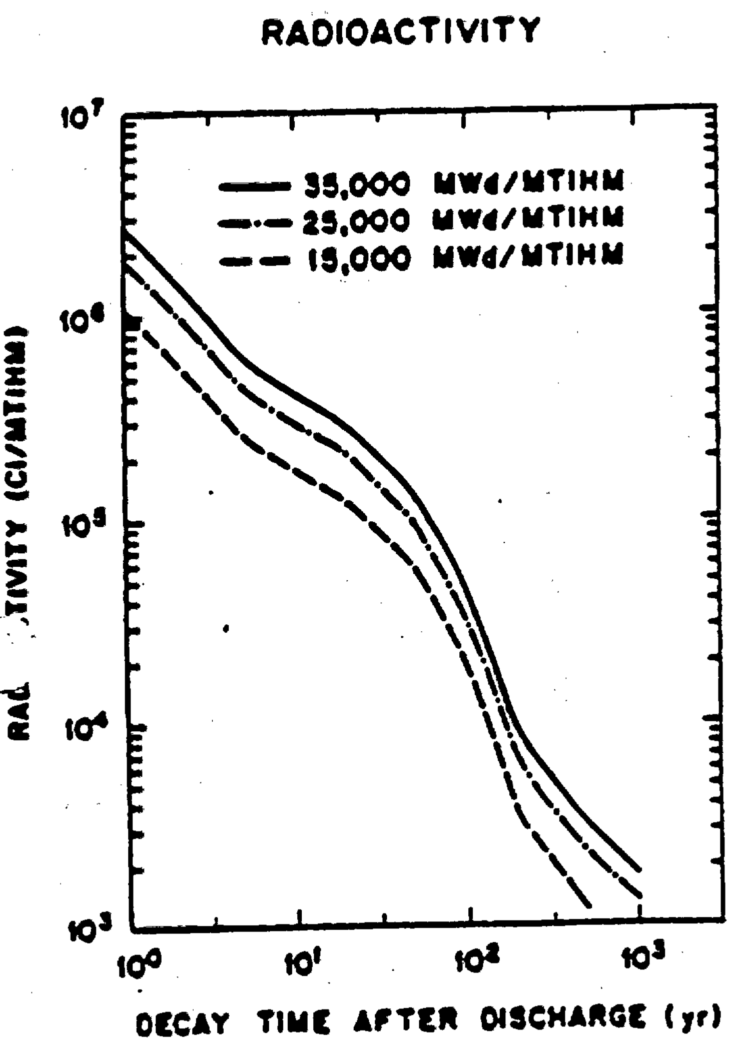

Figure 1 a

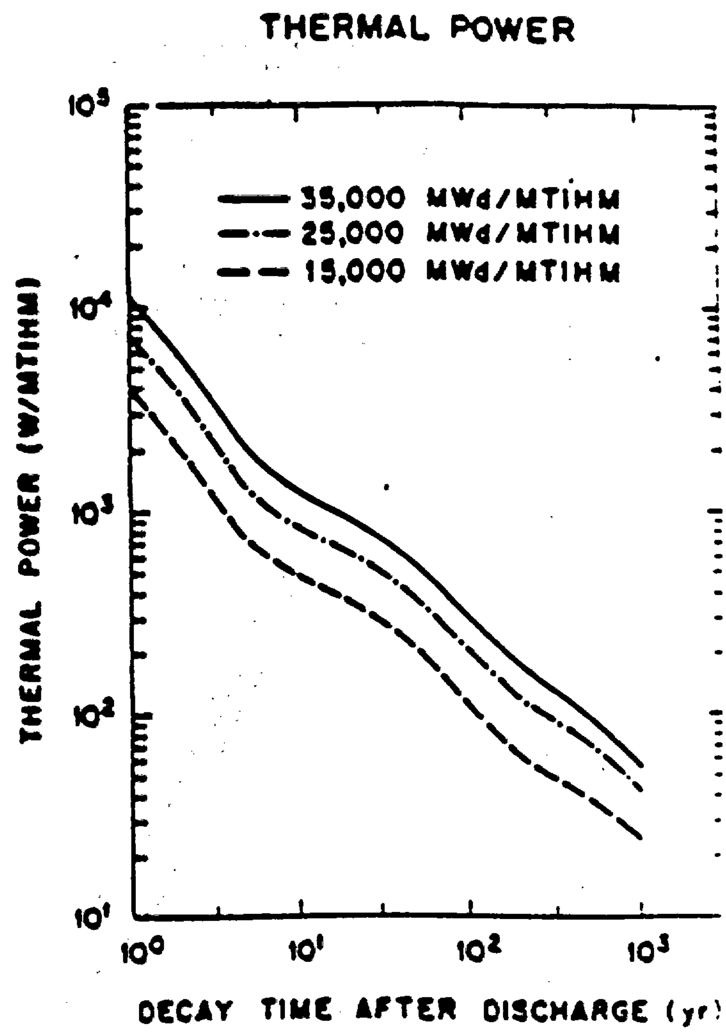

Figure 1 b

Source: DOE/RW-006

BOILING WATER REACTOR SPENT FUEL

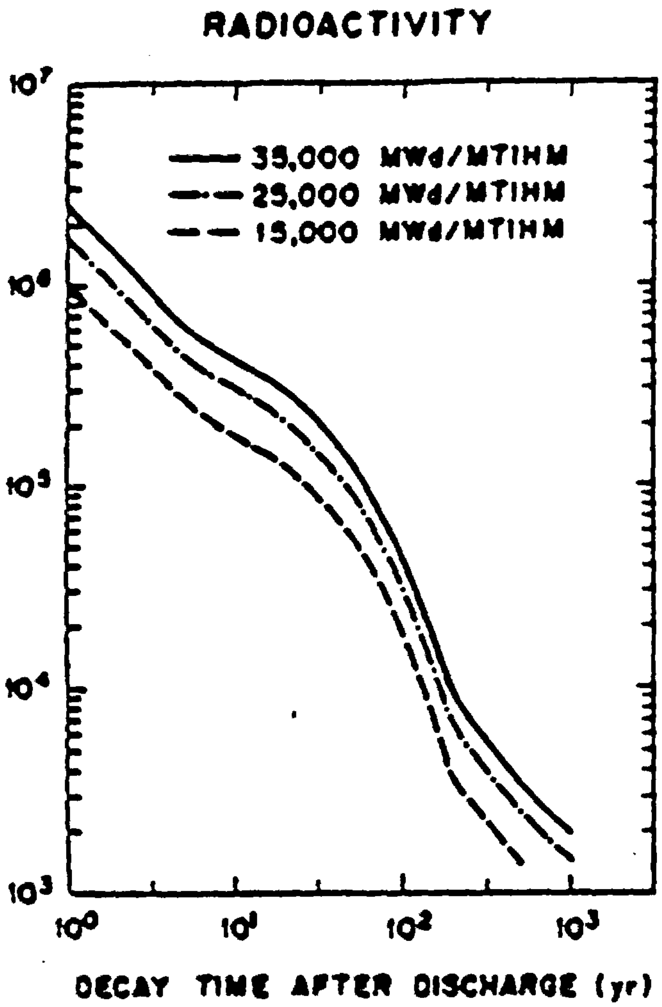

Figure 2 a

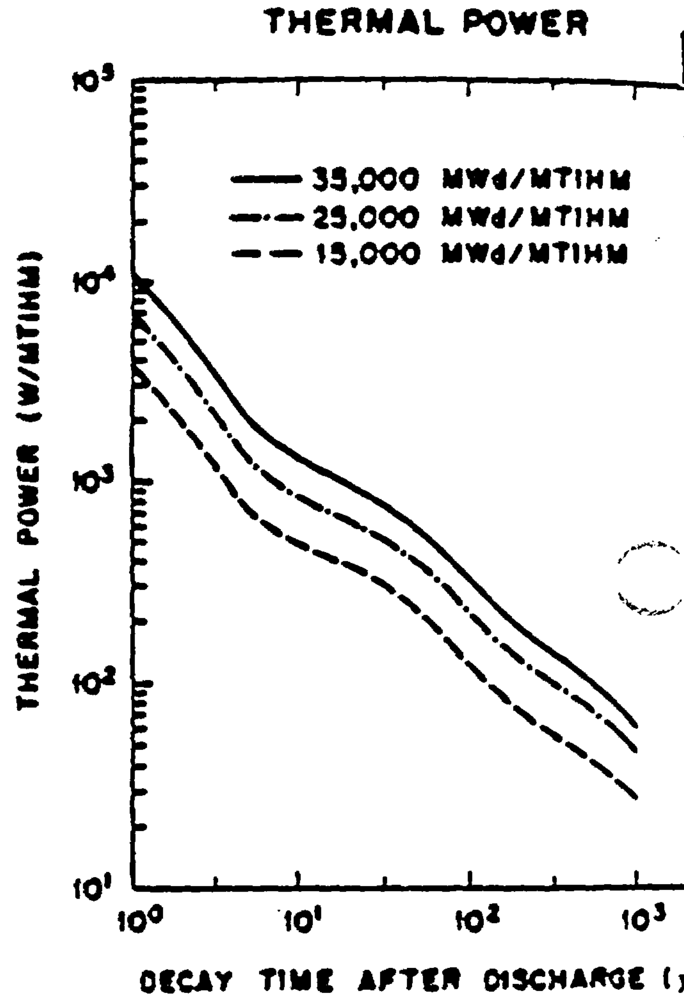

Figure 2 b

Source: DOE/RW-006

1. Krypton-85 (half-life, 10.7 years), cesium-137 (half-life 30.2 years) strontium-90 (half-life 28.8 years) and plutonium-241 (half-life 14.4 years). These elements constitute the bulk of the radioactivity after a few years of discharge from the reactor. (Plutonium-241 decays into other radioactive elements with much longer half-lives, called "daughter products". Pound for pound, the radioactivity in its daughter products is much less than in plutonium-241 itself, because the daughter products decay over much longer time periods.)

2. Very long-lived beta and gamma radiation emitting elements, including carbon-14 and long-lived fission products like technetium-99, iodine-129 and cesium-135 which have half-lives of thousands of years to millions of years;

3 Long-lived alpha radiation emitting elements like radium and radon as well as transuranics like plutonium-239.

Krypton-85, strontium-90, cesium-137, and plutonium-241 present special threats because they are present in very large quantities compared to all the other radionuclides in terms of their radioactivity. Further, strontium and cesium mimic calcium and potassium respectively in the human body and can replace them. For instance, radioactive strontium accumulates in the bone, increasing the risk of bone cancer and leukemia.

One important distinction between isotopes of the same element with long and short half-lives is that the radioactivity per unit weight is inversely proportional to the half-life. For example about 76,000 times more cesium-135 (half-life 2.3 million years) is required to cause the same damage as a specified quantity of cesium-137 (half-life 30.2 years).

As of 1988, U.S. nuclear power reactors had discharged a total of about 13,000 tons of spent fuel, mainly stored in spent fuel pools at the reactor sites. The total radioactivity in this spent fuel assuming an average time after discharge of about 5 years and an average irradiation of 25,000 megawatt-days is on the order of 5 billion curies.

B. HIGH-LEVEL WASTES

High-level waste from reprocessing operations are present at four locations in the U.S.: the Savannah River Plant in South Carolina; the Hanford Reservation in Washington State; the Idaho National Engineering Laboratory; and at West Valley, New York.

At the first two locations, the wastes are mainly from plutonium production for nuclear weapons. At Idaho, they are wastes from reprocessing of spent fuel from naval reactors; at West Valley they are the waste from the reprocessing of some commercial spent fuel and some military spent fuel that was done there between 1966 and 1972. The reprocessing plant has been shut down since 1972.

Figure 3a shows the volume of high-level wastes at the various sites, and Figure 3b shows the total radioactivity for 1983. While the volume at Hanford is larger, about 60% of the radioactivity in the wastes at Savannah River.

The wastes are stored in various forms at these sites. At Savannah River the wastes are in the form of liquids, sludge and salts resulting from evaporation. At Hanford, in addition to these waste forms, there are capsules of separated cesium-137 and strontium-90. At Idaho there are some high-level liquids and powder resulting from calcining liquid high-level waste. At West Valley, the waste consists of liquids and sludge.

The wastes at West Valley are being mixed with molten glass and cast into large cylinders (the process is known as glassification or vitrification). The glass used is borosilicate glass, which is similar to the Pyrex glass used to make kitchenware. A plant to do the same is being built at Savannah River. There are plans to do the same at Hanford but no firm schedule has been announced.

As of 1983, there were about 80 million gallons of mainly military high-level waste, containing about 1.3 billion curies of radioactivity.

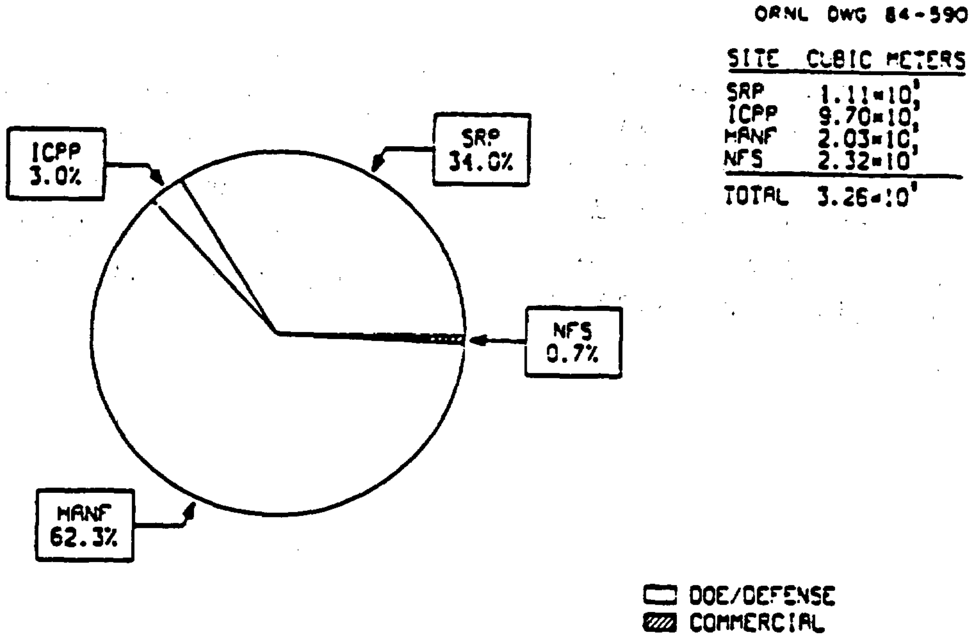

Fig. 3 a. Total volume of HLW through 1983.

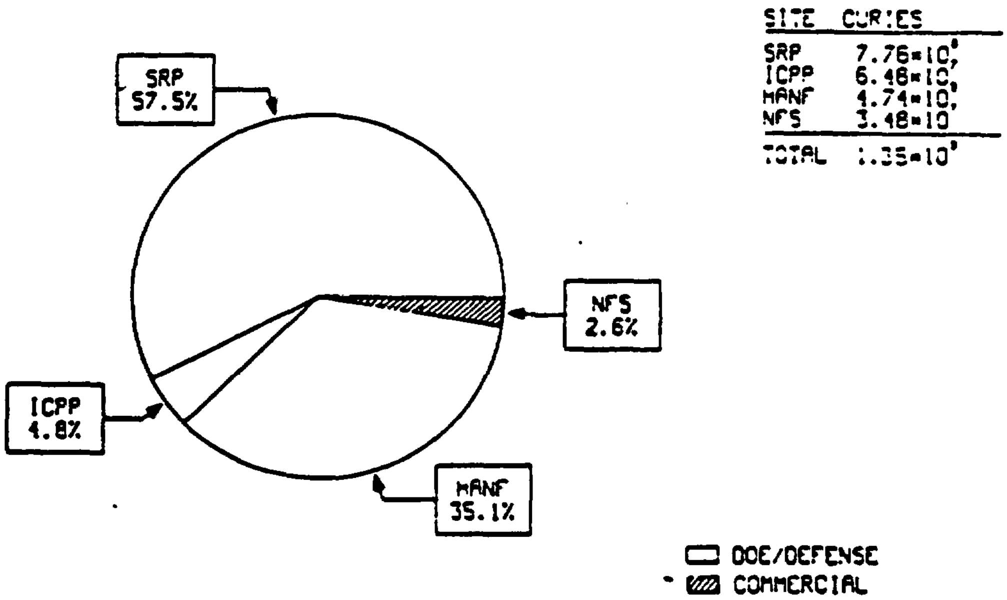

Figure 3 b. Total radioactivity of HLW through 1983.

Source: DOE/RW-006

Key: SRP= Savannah River Plant
Hanf= Hanford
ICPP= Idaho Lab
NFS= West Valley Plant

Much of this radioactivity consists of elements with half-lives on the order of one year or less. However, a considerable portion consists of cesium-137 and strontium-90, which are among the most troublesome radionuclides from the point of view of long-term management. In addition, significant quantities of very long-lived fission products and transuranics are also present.

CHAPTER 3

PERFORMANCE STANDARDS FOR ISOLATION

The purpose of putting high-level nuclear wastes into a repository is to isolate them from the human environment. While the purpose appears to be straightforward, arriving at clear definitions that can be translated into health risks for people and into technical performance criteria for isolation is much more difficult.

To begin with, the half-lives of the longest lived radioactive elements of concern extend for millions of years. It is impossible to guarantee isolation for such time periods. "Isolation" then becomes a relative term in which we assume that some radioactivity will be released to the environment over time.

The questions of what the planning horizon should be, the quantities of radioactivity released and the ways in which they could affect human beings are not only very complex in themselves; they are rendered even more difficult by the long timespans over which assessments are required and the great uncertainties inherent in any such estimates, given our present state of understanding.

The primary criteria and performance standards must relate to health and the environment, since their protection is, after all, the goal of long-term waste management.

In view of this goal, a reasonable approach to defining the performance criteria for a repository would first specify maximum acceptable health risks. Only in the light of such a criterion could technical performance standards be developed for a repository, since these relate to the integrity of the containment of the wastes in the waste packages and in the repository before it reaches any place where it might affect humans.

Only after both health risk criteria and technical performance standards have been developed can the performance of specific waste container designs and repository sites be evaluated. The Nuclear Waste Policy Act of 1982, with its sense of urgency to get the process moving, was quite deficient in this regard.

It asked the Department of Energy to submit a list of sites for the first repository within six months after the promulgation of the Act. However, it did not require the Environmental Protection Agency (EPA) to come up with final standards for protection of human health and the environment until one year after promulgation. Further, the Nuclear Regulatory Commission (NRC) was to come up with technical performance standards for the repository at about the same time as the EPA was to issue its health standards.[8]

In theory, the DOE guidelines for site selection and the NRC standards can be revised to conform to the EPA standards. In reality, once the process of site selection is well advanced, the pressures to come up with health standards that are compatible with prior site selection and technical performance standards would be considerable. In fact the EPA appears to have admitted as much. The 1983 National Academy study by the Waste Isolation Systems Panel of the National Academy of Sciences had already criticized the proposed EPA standard which had been published in December 1982:

> "...[T]he proposed standard is considered by the EPA staff to be 'technology-based, not risk based'...and the standard represents EPA's best estimates of how well a repository can be expected to perform without necessarily considering the risks that may develop from the releases (D.J. Egan, Environmental Protection Agency, personal communication to T.H. Pigford, 1981)."[9]

This is an extraordinary admission by the EPA staff. It states that a rather inadequate and at best questionable assessment of repository performance, at a site not yet selected, much less thoroughly studied, has been the basis for its standard for protecting health. Further, the standard is expressed in terms of fatalities over 10,000 years, and ignores protection of people's health over the million or more years for which the danger from the waste will persist. As we shall see, the health risks from the now-defunct EPA standards could be considerable.

In practice, the outcome has been even worse than the mismatch already present in the Nuclear Waste Policy Act. The NRC issued its final performance standards while the EPA standards were still in draft form. The National Academy Panel rejected using the NRC standards in its own evaluation of geologic isolation partly because it found them inadequate (see below), and also because of the mismatch in timing of the promulgation of the NRC regulations and EPA standard:

> "In reviewing the NRC's proposed regulations, we conclude that they are premature in that they purport to implement an overall EPA standard not yet issued and not yet subjected to the review process wherein the bases and merits of the standard can be fully examined."[10]

As it turned out, a part of the review process was a lawsuit which charged that the EPA standards did not meet health and environmental standards required by other laws. The challenge was upheld and the numerical EPA standards were repealed. So the situation is at a rather absurd technical and regulatory juncture. There are no health standards relating to a repository, but final technical performance standards for the waste package and the repository have already been approved the NRC. Even worse, a single site, Yucca Mountain in Nevada, is being investigated for conformity with the NRC performance standards which relate to unknown health and environmental standards. To top it all off, a $1 billion contract has been issued for beginning the design of the repository at Nevada (see Chapter 5).

The Alice-in-Wonderland nature of this process is brought out by a recent comment by the NRC on DOE's site characterization efforts in Nevada. The NRC noted that "it is our understanding that DOE prepared the CDSCP [Consultation Draft Site Characterization Plan] on the vacated [EPA] standard." It went on to say that the "NRC considers this approach reasonable" and that only "departures from this standard need to be examined by the DOE."[11] The NRC does not explain why it is "reasonable" to proceed on the assumption of a fundamentally flawed standard which has been thrown out by the courts. Indeed, this whole matter can only be understood in the context of the reverse logic with which the whole operation is now proceeding.

A. ENVIRONMENTAL PROTECTION AGENCY STANDARDS

We will not dwell at any length upon the EPA standards since the question has been remanded to the EPA for revision. However, it worthwhile noting that the draft standards were poor both in relation to health and for their lack of consistency with the performance criteria that NRC had already issued. The draft EPA standard proposed that there be no more that 1,000 fatalities per 10,000 years as a result of all releases associated with a full-scale repository containing 70,000 tons of waste.[12]

There are many flaws in this approach. Even before the standard was issued, the National Academy Panel was privy to the analysis of the EPA. It strongly criticized the proposed standard and rejected using it in its own study of the problem.[13] Among the flaws discussed by the National Academy Panel were assumptions such as:

- o diets would not change for 10,000 years;
- o world average diets, instead of site specific diets would be used to calculate fatalities;
- o rate of use of contaminated water would be the same as that of uncontaminated water;
- o soil retention characteristics are independent of the site.

These assumptions are not only unrealistic; some of them, such as the ones relating to retention of radionuclides in the soil and the use of world average diets are scientifically unjustifiable.

In addition, the standard arbitrarily restricted the time horizon to 10,000 years when a number of radionuclides of concern have much greater half-lives. Further, some radionuclides such as radium-226 are generated as decay products of others. As a result, the radiation doses from radium may not peak until a million years after a repository is built, even though the half-life of radium-226 is 1,600 years.

Further, the specific time span chosen -- 10,000 years -- does not match with the NRC performance criteria for repository performance, which require some degree of containment of the radionuclides for up to 100,000 years.

The National Academy Panel summed up its critique of the EPA standards by noting that, depending on the actual conditions and time interval in which the radionuclides were released from the repository, the doses from important radionuclides could range from negligibly low amounts, which would be essentially undetectable, to as much as 100 sieverts (10,000 rem) per year -- essentially a lethal dose.[14]

Thus, the EPA standard to which the DOE is supposed to have accommodated its site selection and repository design criteria was so flawed and arbitrary as to be meaningless as a criterion for a realistic assessment of damage to public health. Yet this continues to be the de facto standard, even at present.

One of the most remarkable things about the process of promulgating the standards was that the EPA ignored this severe and thorough critique of its proposed standard by the National Academy of Sciences Panel in its 1983 study and proceeded to finalize the standard in 1985 without significant change. Eventually, the flawed standard was invalidated by the courts on yet other grounds in 1987.

B. NUCLEAR REGULATORY COMMISSION PERFORMANCE STANDARDS

The NRC waste package and repository performance standards are as follows:

- o retrievability during waste emplacement in the repository and after closure until "significant uncertainties...have been resolved, thereby providing greater assurance that the performance objective will be met."[15]

- complete "containment of HLW [high-level waste] within the waste packages...for a period...not less than 300 years nor more than 1,000 years after permanent closure of the geologic repository."[16]

- the release rate from the "engineered barrier system" of all radionuclides remaining in significant quantities after 1,000 years "shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present after 1,000 years following permanent closure."[17]

- the "pre-emplacement" travel time of groundwater along the fastest likely path "shall be at least 1,000 years or such other travel time as may be approved or specified by the Commission."[18]

These performance standards were supposed to be based on the presumed EPA standard which related to number of deaths over 10,000 years. It is clear, however, that the standards do not relate to the same time intervals. The most stringent aspect of the NRC standard relates to zero release the first 300 to 1,000 years, but there are no corresponding health criteria. Secondly, the NRC specifies performance up to 100,000 years for the engineered barriers but the health criteria only extend to 10,000 years. Moreover neither of them relate to the dangers posed by the actual inventory of radionuclides in spent fuel.

Again the 100,000 year NRC criterion for containment of radioactive waste does not relate to the characteristics of the waste. There is no logical reason to demand perfect containment for the first 300 to 1,000 years and then none at all after 100,000 years, in spite of the persistence of considerable quantities of radioactivity for much longer periods.[19]

Table 1 shows the principal radionuclides in one spent fuel assembly from a pressurized water reactor. The quantities would be somewhat less in a typical boiling water reactor assembly, but

	Time After Discharge					
	10 yr		100 yr		1,000 yr	
Nuclide	g	MBq	g	MBq	g	MBq
^{14}C	1.6×10^{-1}	2.5×10^{4}	1.6×10^{-1}	2.5×10^{4}	1.4×10^{-1}	2.3×10^{4}
^{79}Se	2.7	7.0×10^{3}	2.7	7.0×10^{3}	2.7	6.9×10^{3}
^{90}Sr	2.0×10^{2}	1.0×10^{9}	2.3×10^{1}	1.1×10^{8}	~ 0	~ 0
^{99}Tc	3.6×10^{2}	2.3×10^{5}	3.6×10^{2}	2.3×10^{5}	3.6×10^{2}	2.3×10^{5}
^{126}Sn	1.3×10^{1}	1.3×10^{4}	1.3×10^{1}	1.3×10^{4}	1.3×10^{1}	1.3×10^{4}
^{129}I	8.3×10^{1}	5.3×10^{2}	8.3×10^{1}	5.3×10^{2}	8.3×10^{1}	5.3×10^{2}
^{135}Cs	1.4×10^{2}	6.3×10^{3}	1.4×10^{2}	6.3×10^{3}	1.4×10^{2}	6.3×10^{3}
^{137}Cs	4.4×10^{2}	1.4×10^{9}	5.5×10^{1}	1.8×10^{8}	~ 0	~ 0
^{226}Ra	1.6×10^{-7}	5.4×10^{-3}	1.2×10^{-5}	4.2×10^{-1}	1.4×10^{-3}	4.9×10^{1}
^{234}U	8.8×10^{1}	2.0×10^{4}	1.2×10^{2}	2.7×10^{4}	1.5×10^{2}	3.3×10^{4}
^{238}U	4.4×10^{5}	5.4×10^{3}	4.4×10^{5}	5.4×10^{3}	4.4×10^{5}	5.4×10^{3}
^{237}Np	2.1×10^{2}	5.4×10^{3}	2.7×10^{2}	7.2×10^{3}	6.6×10^{2}	1.7×10^{4}
^{238}Pu	6.0×10^{1}	3.7×10^{7}	3.0×10^{1}	1.8×10^{7}	2.6×10^{2}	1.8×10^{4}
^{239}Pu	2.3×10^{3}	5.3×10^{6}	2.3×10^{3}	5.3×10^{6}	2.3×10^{3}	5.1×10^{6}
^{240}Pu	1.1×10^{3}	8.7×10^{6}	1.1×10^{3}	8.7×10^{6}	1.0×10^{3}	7.9×10^{6}
^{241}Pu	3.5×10^{2}	1.3×10^{9}	4.6	1.8×10^{7}	8.6×10^{-5}	3.6×10^{2}
^{242}Pu	2.1×10^{2}	3.1×10^{4}	2.1×10^{2}	3.1×10^{4}	2.1×10^{2}	3.1×10^{4}
^{241}Am	2.3×10^{2}	2.9×10^{7}	5.0×10^{2}	6.4×10^{7}	1.2×10^{2}	1.5×10^{7}
^{243}Am	4.0×10^{1}	2.8×10^{5}	3.9×10^{1}	2.8×10^{5}	3.6×10^{1}	2.6×10^{5}
^{245}Cm	5.6×10^{-2}	3.5×10^{2}	5.5×10^{-2}	3.5×10^{2}	5.1×10^{-2}	3.3×10^{2}
^{244}Cm	4.3×10^{-2}	4.9×10^{2}	4.3×10^{-2}	4.9×10^{2}	3.7×10^{-2}	4.2×10^{2}

Table 1. Significant Radionuclides on One PWR Spent Fuel Assembly.

Source: NAS, 1983

the composition is similar. Figure 4 shows estimates, made by the National Academy Panel, of doses from various radionuclides under one set of assumptions about radionuclide releases. Under these assumptions, significant doses from neptunium-237 peak a little after 100,000 years and extend well beyond that; doses from cesium-135 peak at almost 1 million years. The release criteria should be radionuclide specific and take into account the inventory of the radionuclide at various times, the half-life of the radionuclide, its chemical properties, its toxicity, and other factors that would affect the danger that it poses to human health.

C. NATIONAL ACADEMY OF SCIENCES APPROACH

In view of the essential flaws in the now-defunct EPA standard and the NRC regulations, the 1983 National Academy Panel used its own standard:

> "[T]he most meaningful and useful form of the criterion is the annual or lifetime radiation dose to an individual exposed at some future time to radionuclides released to the environment from a geologic repository. We have adopted as our criterion an annual dose of 10^{-4} Sv [10 millirem] to an individual, averaged over his lifetime, calculated at all future times."[20]

While the specific numerical limit needs further scrutiny and debate, the National Academy Panel's approach is a sound one, because conformity with it will actually place an upper limit to the amount of health damage to any individual from radioactive waste for all time.

The dose limit chosen by the National Academy Panel is about 10% of the natural background radiation. This is a significant amount for any individual, even though it is well within the limits of natural variation. A dose of 10 millirem to a pregnant woman, for instance, might affect the fetus much more than the averages over a lifetime would indicate. Moreover, one cannot assume that the substantial variations in natural background radiation are not harmful. They may well be responsible for some

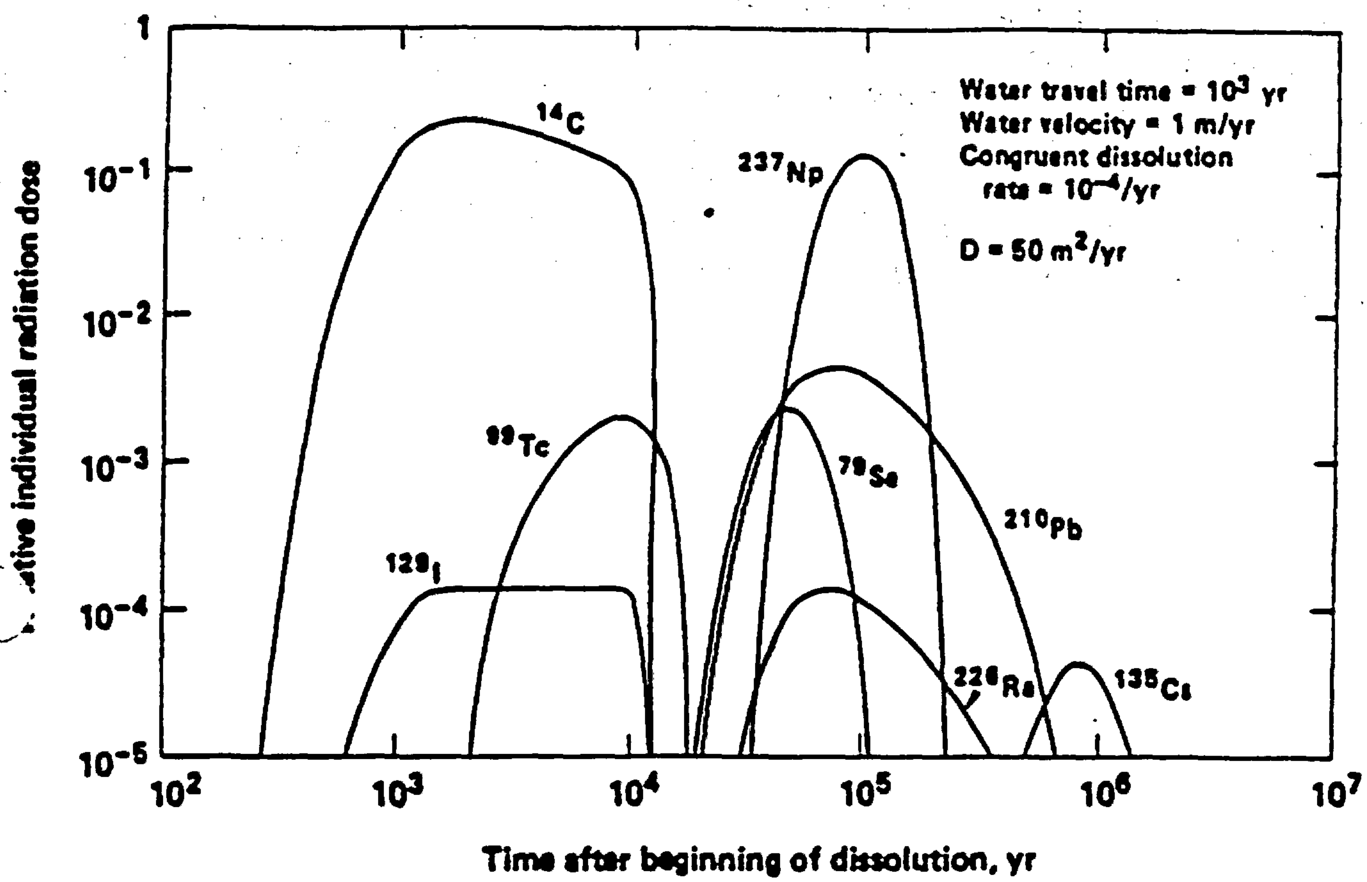

Figure 4. Relative individual radiation dose as a function of time: reprocessing waste from 10^5 Mg uranium fuel in basalt, congruent dissolution.

Source: NAS, 1983.

portion of the cancers and genetic disorders that seem to occur spontaneously.

We recommend that dose limits be set in light of those especially at risk -- pregnant women and fetuses. That is, risk of cancer, genetic problems and other diseases should be assessed assuming that the level of dose will begin at or close to conception and last throughout life. We also recommend that overall exposures from all fuel cycle activities, military and civilian, be limited to a smaller fraction of both natural background and the variations in it (which happen to be of the same order of magnitude) than the standard of 25 millirem per year.

CHAPTER 4

SITE SELECTION

The Nuclear Waste Policy Act of 1982 mandated a search for sites which would lead up to the construction of two repositories. The first was to begin operation in 1998. The nomi: :tions for characterization for the first site were put on a very fast track -- guidelines for site selection were to be promulgated within six months and three sites were to be selected for detailed characterization, which would involve enormous expenditures, by January 1, 1985. The schedule for selecting three locations for characterization for the second repository was less stringent: DOE was to submit a list for presidential approval by January 1, 1989.[21]

The purpose of this chapter is to provide sufficient typical examples of how the DOE went about selecting sites for characterization. This will provide some understanding of why the process failed and what institutional characteristics the DOE might possess that contributed to that failure.

A. FIRST ROUND SITES

The unrealistic schedule in the 1982 Nuclear Waste Policy Act for issuing guidelines reinforced DOE's proclivities to assume that the sites it was already considering would be acceptable, regardless of known adverse facts, resource-use conflicts, and other difficulties. DOE issued guidelines that would, if not applied too carefully or stringently, create a high chance that whatever sites it had been examining at the time would become acceptable for characterization for the first repository.

Most of those sites were in salt formations. There was considerable evidence that these formations would pose serious difficulties, such as problems of retrievability of waste in case of unforeseen difficulties, of inadequate waste confinement due to the presence of brine, and of resource conflicts in several cases. Yet DOE included these salt sites. It also included two areas where the politics appeared to favor site characterization: the federal reservation at Hanford, Washington, and the Yucca Mountain site located on the border of the Nevada Test Site for nuclear weapons testing. Both of these areas contained rock types different from salt and from each other; both also happen to be very complex geologically, and hence difficult to characterize with confidence.

The composition of the sites made it inevitable that Hanford, Yucca Mountain, and one salt site would be among the three selected for characterization. But there appeared to be no salt site free of problems that would not disqualify it under the strictures of the Nuclear Waste Policy Act. For instance, the Utah site was near a National Park. The salt site nominated for characterization was in a prime agricultural area in Deaf Smith County, Texas; it was above the largest aquifer in the U.S. (the Ogallala aquifer) from which a large region of the Southwest draws its drinking and irrigation water. The selection of the Deaf Smith site was untenable on that score alone; there were a number of other potential problems as well.

We will illustrate the problems with the first round sites by focussing on the non-salt sites: Hanford, Washington, and Yucca Mountain, Nevada. The latter is discussed in a separate chapter because in 1987 Congress amended the 1982 Nuclear Waste Policy Act to restrict site characterization activities to just that one site. The possibility of characterizing other sites is to be investigated only in case Yucca Mountain turns out to be unsuitable under as yet unspecified EPA standards.

The selection of Hanford despite evidence of major problems is one example of the Department of Energy ignoring or deliberately sidestepping evidence to select what seemed to be a politically convenient site. The National Academy Panel had already pointed out numerous problems in its 1983 study, including high rock stresses and evidence of sudden failure of the rock in the form of rock samples ruptured into chips or discs ("core-discing"). It concluded that high rock stresses and the discing of the cor samples might portend problems such as rock bursting and associated problems for meeting repository standards.

The DOE appears to have assured the Academy that it was addressing the problems, but the Academy panel was not so sure, for it noted:

> "It is the understanding of the panel that the cause and design consequences of the core discing are now being addressed. We note however that the problem has been known for some time (Myers and Price 1979)."[22]

In the event, the Department decided to fudge the data on rock stresses and, essentially, to continue to ignore the problem. In its Site Characterization Report for Hanford, DOE used the lowest measurement for rock stress. It omitted all higher measured values to justify inclusion of the site and to avoid discussing the implications of its own conclusion that stresses near the maximum measured values might render the construction of a repository at Hanford "economically unattractive."[23]

Similarly, the Department had been warned for years prior to 1984 by the U.S. Geological Survey,[24] by a study done for the Nuclear Regulatory Commission,[25] and independent hydrogeologists that vertical flows of water needed considerable study and that there were indications that such flows may greatly accelerate the transport of radionuclides to the Columbia River and generally to the human environment. The DOE chose to largely ignore this problem in tentatively selecting Hanford as one of the top three sites in December 1984 and then confirming that decision in 1986.

We have some rather unusual evidence of a DOE effort to manipulate the Performance Assessment for the Hanford site. In reviewing an internal draft of the Performance Assessment in October 1984, a Weekly Status report found that the Performance Assessment "has emerged as a major problem."[26] The internal memorandum then goes on to discuss the nature of the "major problem" and how to fix it.

One of the major problems that DOE internal reviewers found with the Performance Assessment written for the Hanford Site was, apparently, that it was too clear in expressing the inadequacies of the site. The editorial advice (straight out of Orwell) was to obfuscate:

> "The use of Level II language is needed in the text (as indicated in the Siting Guidelines) (i.e. never conclude anything; use double negataives [sic] -- e.g.,...it is not indicated that the following condition has not been met)."[27]

In addition, the reviewer advised that the Performance Assessment might have been too good, in that it "goes beyond what HQ asked them to do. Their approach is more complicated and results in answers that do not satisfy NRC and EPA requirements for release of RN [radionuclides] from the repository."[28]

This statement is revealing of the DOE approach. The Draft Performance Assessment for the Hanford site seems to have revealed too many problems. Instead of intensifying investigation of the problem areas to see if they might indicate the presence of conditions which might seriously compromise isolation of radioactive wastes, the recommendations were to change the method. The people doing the Hanford Assessment were directed to "do a complete set of analyses associated with the more complex approach in order to reduce the RN [radionuclide] release."[29] Thus while appearing to endorse a more complete investigation, the clear direction was that the conclusion of the analysis had already been determined -- it should show a reduction of the estimate of radionuclide releases.

That memorandum was written in October 1984. Two months later, when the DOE issued its Draft Environmental Assessment for the Hanford site, it downplayed and ignored many serious problems and, as noted above, manipulated rock stress data to make the site appear much better than it was.

It is also interesting to note that the estimate of radionuclide releases is written about as if it were the actua radionuclide release. The record indicates that DOE frequently confuses wishful estimates and reality.

B. THE SECOND ROUND SITES

With much more time to prepare its list of sites, to prepare a method for site selection, and to study the public literature, governmental and non-governmental, carefully, one would have thought that the process for selecting the potential sites for the second repository would be better than that for the first, and that the recommendations would be technically sounder. They were not.

DOE issued a Draft Area Recommendation Report in January 1986[30] which, if anything, exceeded the earlier first repository documents in its sheer incompetence and neglect of known facts. To begin with, it ignored much of the published literature on site selection, including literature specific to sites in the East, South and Midwest.

This exclusion included its own studies, studies by the U.S. Geological Survey, and much other relevant public literature. It even excluded one of the most authoritative overviews of the problem of geologic isolation which had been produced until that time -- the study done by the Waste Isolation Systems Panel of the National Academy of Sciences, published in 1983. Indeed, the only National Academy study cited was a 1957 report!

It is unlikely that the exclusion of this literature was arbitrary or mere ignorance. The excluded literature was too large in quantity, too public and well-known, and only too relevant for that. For instance, DOE decided to exclude the kinds of geologic formations that had been recommended by both the National Academy Panel in 1983, and again by a study specially done by the U.S. Geological Survey in 1984 to assist the Department of Energy in its site selection process.[31]

Both these studies recommended that the most promising kind of geologic formation involving crystalline rocks (granite and related rocks) was a hybrid formation in which a deep granite rock formation was overlain by 1,000 to 4,000 feet of sedimentary rock aquifer. This reasoning was that the behavior of the sedimentary layers was well understood and could be modelled with much greater confidence compared to crystalline rocks. The National Academy Panel's study also pointed out that if the aquifer consisted of brackish water, as many such formations did, then the possibility of human intrusion would be minimized. The rock formations were also thought to have a number of other advantages such as low water flow rates, poor prospects for oil and gas, etc.

Both the National Academy and the U.S. Geological Survey studies recommended these formations for evaluation since they would secure the potential advantages of granitoid rocks in terms of their isolation properties, but overcome one of the principal defects of granite formations -- complexity. Purely granite formations, such as those selected by DOE for possible repository locations, have long been known to be so complex as to make site characterization very difficult and the results of such characterization quite uncertain.

It was, in large measure, to reduce this uncertainty that both the U.S. Geological Survey and the National Academy Panel had recommended study of hybrid rock formations. For instance the Panel noted:

> "Each of these single rock types, such as granitoid alone, has major uncertainties, such as location, character, and irregular distribution of flow channels, that are exceedingly difficult to predict or model with confidence."[32]

Uncertainty goes to the heart of the problem of geologic isolation. Our understanding of geologic processes and of the interaction of nuclear waste with the geologic environment must be good enough to provide reasonable assurance that the standards that are set for the protection of the health of future generations will be met. This point has long been emphasized by geologists. For instance, Witherspoon, Cook and Earl stressed it in a 1981 paper thus:

> "Ultimately, the ability to characterize the geologic system may dictate the choice of the best rock for a repository and the disposal system.
>
> ...
>
> "The need for a basic understanding of rock behavior under the special conditions that will arise in an underground repository containing heat generating, radioactive waste and of the complex processes of waste migration in slowly moving ground waters cannot be overstated."[33]

Yet DOE chose to ignore all this advice. It completely excluded hybrid formations because it would require deep drilling and thus be too "time-consuming". It opined that exposed crystalline rocks, which it chose, would be faster to study because there was "more information about them" (much of which it ignored!) and because such rocks "can be mapped, studied and sampled directly".[34]

Of course, the real complexity of the sites, the various problems that might exist in every one of them and the immense difficulties which would confront their resolution, including a lot of time-consuming drilling could not be denied by ignoring the literature and hoping that no one would notice. In any event, the political and technical storm caused by the site selection and its faulty methodology forced DOE to abandon the search for a second repository altogether in May 1986. This set the stage for a revision of the Nuclear Waste Policy Act and the narrowing of the search to just one very complex site: Yucca Mountain in Nevada.

CHAPTER 5

THE YUCCA MOUNTAIN SITE IN NEVADA

A. TECHNICAL ISSUES

The principal presumed advantage of the Yucca Mountain site relates to the plan to locate the repository above the water table. With the additional assumption that present-day dry conditions will persist for tens of thousands of years, the outlook for waste containment was presumed to be very promising. In addition, it was thought that the little water from rain and melting snow that does percolate through the proposed repository site could be channeled around the waste, keeping the waste out of contact with water. A repository that accomplishes this favors successful isolation of radioactive wastes from the human environment, since water is generally presumed to be the principal means of transport of radionuclides.

Luther Carter, whose book and articles on nuclear waste were influential in the Congressional decision to narrow the search to one site put it thus in one article:

> "Yucca Mountain offers an important advantage in that much of it is high above the water table in a desert region of little rainfall. DOE and the U.S. Geological Survey believe, but must now confirm, that little or no water will infiltrate downward from the surface to the repository. If no water comes in contact with the waste canisters or casks, there would be no corrosion, and no mechanism for radionuclide transport."[35]

The matter appeared to be very simple: a dry repository in a desert with little rainfall, (coincidentally on a site on Federal land and in a state with relatively little political muscle in Congress!) would contain the waste well. It seemed a safe bet to restrict the search to one site that appeared promising and get rid of the myriad political headaches that had attended the wider effort.

It was as a result of these presumptions (and, of course, a number of political considerations) that Congress decided to take a chance on sequential characterization and restrict the effort to the Yucca Mountain site.

But few things in geology are simple or predictable. And the matter can never be resolved without the utmost dedication and competence to gather the relevant data and to make analyses of great technical integrity. However, the available evidence is indicates that DOE is operating its Nevada characterization in a manner that is entirely consistent with its prior dismal record in the nuclear waste arena. We discuss below some of the evidence for this conclusion.

Even as Congress was considering, in late 1987, restricting site characterization to the Nevada site alone on the premise that it would be suitable, a DOE scientist in its Nevada Operations Office, Jerry S. Szymanski, had finished an internal report warning of serious potential problems which the Nevada site might face.

Szymanski's report, dated November 1987, throws doubt on the very premises and on the method by which DOE's conclusion about probable site suitability was derived. (The Yucca Mountain site had been at the top of the list in the DOE ranking of the various First Round sites.) The Szymanski report was ready in DOE's Las Vegas Office a month before Congress decided to risk confining site characterization to Yucca Mountain. But DOE did not make it public at that time. Indeed, it was leaked a few months later, after Congress had already acted.

Based on an extensive investigation of available data, the Szymanski report warned that the assumption that the repository would remain dry for the duration that confinement was required was highly questionable. It concluded that a rise of the water table of sufficient magnitude to flood the repository had a high enough probability that it should be considered as an "anticipated process and event":

> "...[T]he most important licensing concern is the potential rise of the water table....In this situation, and in the context of the performance requirements set forth in 10 CFR 60 and 40 CFR 191 [the NRC and EPA standards], the rise of the

> water table constitutes an 'anticipated process and event.' As such the rise of the water table must be accounted for in demonstrating compliance of the Yucca Mountain disposal system with...long-term performance objectives...."[36]

Water is generally considered to be the most important pathway for radioactive materials to leave the repository and enter the human environment. The possible rise of the water table to cover the nuclear wastes in the repository would, as Szymanski noted, "significantly alter the radionuclide migration path and the radionuclide migration time....Occurrence of the water rise during the early stages of the life of the repository, when the temperature of the waste packages and the fractured medium surrounding them is above the boiling point of water, would result in a particularly strong impact on the overall repository performance. Vaporization of water entering the repository...would accelerate the gaseous transport from the repository to the ground surface. Subsequent cooling of the repository, to below the boiling point of water, may be accompanied by long term convective flow of fluids from the repository to the ground surface."[37]

There are other ways in which water entering the Yucca mountain repository might have even more adverse consequences than at some other potential sites. According to the National Academy Panel's 1983 study, the composition of groundwater is a "major chemical disadvantage" of the Yucca Mountain site.[38] This is because the "best available" information indicates that Yucca Mountain groundwater would dissolve radionuclides more rapidly than at other sites:

> "In general, their [radionuclides'] solubilities [in Yucca Mountain groundwater] are higher than in other candidate host environments. This could be a distinct disadvantage for a water-saturated environment but has little relevance if the slight recharge can be excluded from direct contact with the waste...."[39]

The National Academy Panel evidently considered the problem of unfavorable water chemistry so disadvantageous that they suggested that even the small recharge from rainwater expected under present conditions be diverted around the waste in the repository. However, the Panel did not consider the problem of the possible rise of the water table. Szymanski's analysis was still years away when the Panel completed its report in 1983.

A further problem that a wet repository could create would be the potential adverse chemical reactions between borosilicate glass and steam. Borosilicate glass is the material in which military high-level wastes are being immobilized at Savannah River.

Under the relatively low pressure that would prevail in the Yucca Mountain repository, water might flash into steam when in contact with the hot waste. Experiments at Argonne National Laboratory conducted several years ago indicate that steam could rapidly disintegrate glass and cause a release of radionuclides.[40]

All of this goes to show that the principal assumption of a dry repository rests on tenuous and questionable assumptions. Further, the risks in case that assumption is not valid are great, in view of the more severe problems that a wet repository might face with compared to some other sites.

Even after committing the country to the risky course of sequential characterization using Nevada, one would think that this problem would receive honest and diligent attention on the part of DOE, because the safety and well-being of future generations depends so much on the assurance that the repository is likely to stay dry. Redoubled efforts to understand the hydrogeology of the site are made even more imperative by the well-known complexity of the site and the limited knowledge about the flow of water in the presently unsaturated zone.[41] Yet, DOE appears to have designed much of its effort so as to avoid finding out the answers to important questions.

The Szymanski report, for instance, points out that the model and site characterization approach of the DOE to the Yucca Mountain site were seriously flawed and would fail to reveal serious problems with the site. His conclusion about the DOE conceptual model, which is important to DOE's presumption about the suitability of the site, was as follows:

> "Examination of the extensive data base pertaining to the Death Valley groundwater system...reveals that this flow field is considerably different than the flow system currently envisaged by the NNWSI [Nevada Nuclear Waste Storage Investigations] Project. The conceptual model of this flow system, as used in performing site suitability assessments for purposes of developing the Final Environmental Assessment for the Yucca Mountain site and for purposes of establishing an approach to the forthcoming site characterization activities, is far too simple and far too removed from reality. **Simply stated this conceptual model ignores completely the volcano-tectonic setting of the Yucca Mountain site.**"[42] (Emphasis added.)

Szymanski's conclusion was clear -- the model that DOE was using was of limited value and, indeed, it might contribute to a misunderstanding of the processes at work:

> "The conceptual model of the flow field, indicated by the currently available data from the Yucca Mountain site, points toward serious limitations of this site to effectively isolate radionuclides from the biosphere. These limitations are greater by far than those currently recognized by the NNWSI Project. Without recognizing these limitations, the issue resolution strategies, as expressed in the current version of the Site Characterization Plan...are of very limited practical value. The resulting misunderstanding of the hydrologic processes...results in overly optimistic assessments of the licensability of the Yucca Mountain site."[43]

There are other indications that DOE's approach would result in evading facts crucial to assessing the capacity of the Yucca Mountain site to meet EPA and NRC standards. For example, the NRC has made much the same criticism as Szymanski:

> "The NRC's most fundamental concern with the CDSCP [Consultation Draft Site Characterization Plan] remains the objection related to the failure to recognize the range of alternative conceptual models of the Yucca Mountain site that can be supported by the existing limited data

> base and that need to be considered in the development of testing programs."[44]

The NRC also found that the draft DOE's Site Characterization Plan exhibited the same bias towards confirming its prior conclusions and towards not-finding out facts that might cast doubt upon them or invalidate them:

> "Although efforts have been made in the CDSCP to identify more than one conceptual model of the Yucca Mountain site, the site characterization plan appears primarily designed to gather evidence in support of a preferred conceptual model rather than to obtain a thorough understanding of the site and the data necessary to reduce uncertainties about which conceptual model best portrays the Yucca mountain site."[45]

The State of Nevada has made basically the same point in its comments on DOE's draft site characterization plan:

> "The document as written fails to ask crucial site suitability questions, lacks the specificity required for an adequate and meaningful review, and, most importantly, attempts to cloud and obscure technical issues and divert attention from potentially disqualifying flaws."[46]

Another telling example is the list of problems brought up by numerous hydrologists and hydrologic technicians who are a part of the U.S. Geological Survey's Nuclear Hydrology Program in its office of Nevada Nuclear Waste Storage Investigations (NNWSI). This office of the U.S. Geological Survey is supposed to provide DOE with scientific evaluations of the hydrological and geological aspects of the site and its suitability or lack of it for a nuclear waste repository.

In spite of this mission, several hydrologists and hydrologic technicians have risked their jobs and their professional reputations by making very serious charges about the conduct of these preliminary stages of the characterization effort. Whatever the procedural and personnel aspects of the dispute, the substance of the memorandum provides further evidence that the practical result of DOE's actions is that data about serious problems are not being gathered and analyzed in a timely manner.

The authors of the memorandum describe their purpose as follows:

> "It is appropriate to refer to the Challenger space shuttle disaster as a profound example of what happens when management is unresponsive to the concerns of the technical staff.
>
> ...
>
> "It is our urgent recommendation that we prevent our own 'NNWSI' [Nevada Nuclear Waste Storage Investigations] disaster by making USGS-NNWSI management aware that in subjugating the technical program to satisfy DOE political objectives, we may succeed in making the program comply with regulations while being scientifically indefensible."[47]

The authors list several specific areas of urgent technical concern. One of them involved collecting data on possible releases of carbon-14 in gaseous form (as carbon dioxide) from the repository. According to present guidelines, these releases are limited to 200 curies in the first 1000 years. Yet, according to the memorandum, actions are being taken which will foreclose the gathering of data important to assessing such releases:

> "Because ^{14}C[arbon] is produced by neutron bombardment of the Zircalloy cladding around spent fuel rods, a real possibility exists that current repository design might fall short of this objective. Personnel at Sandia National Laboratory and the Desert Research Institute are concerned with this problem. Data collection on gas circulation requires open boreholes, but USGS-NNWSI has forbidden such data collection until paper work is completed, at which time boreholes are to be sealed. Thus USGS-NNWSI management seems unconcerned about losing potentially irretrievable data, in this case data on gas circulation, to the detriment of scientific evaluation of the site."[48]

The memorandum cites an example of work which has been suspended in a critical area relating to possible unanticipated water entry into the site arising from presently unexplained hydraulic gradients:

> "For a distance of several kilometers north and east of the design repository, the horizontal hydraulic gradient of the water table is about .15, whereas downgradient from Yucca Mountain, the hydraulic gradient is about .0001....Because the repository will be located between about 100 to 400 meters above the water table, and because it will be located immediately downgradient from the steep hydraulic gradient [of .15], the stability of the nontransmissive property of this barrier to ground water flow is of primary importance....While NNWSI has been receptive to motions advocating the examination of the steep gradient, nothing new is now being done to assess this critical issue which has the potential of disqualifying the site. Any further interpretation of the steep gradient based on water-level data is currently forbidden by the stop-work order."[49]

In plainer terms, this unexplained phenomenon raises the possibility that the location of the repository 100 to 400 meters above the present water table level may not guarantee a dry repository. The presence of steep hydraulic gradients close to or even within the general region of the proposed repository location indicate a hydrogeologic regime that is even more complex than had been anticipated -- and complexity was already one of the serious problems with the Yucca Mountain site.

A considerable portion of the disagreement between these scientists and the DOE appears to relate to whether the effort would be treated from the beginning as a scientific investigation whose outcome is unknown, or whether there should be a presumption that the outcome will be favorable to the project, in which case the effort would be treated as part of a long-term construction project for a repository.

That DOE is of the latter inclination is indicated not only by the NRC and other documents cited above, but also by the rather premature granting of a billion-dollar contract to a team of corporations led by Bechtel (the world's foremost builder of nuclear power plants) to design, engineer and operate a repository at Yucca Mountain.[50]

Given the great uncertainties, complexity, uniqueness and potential consequences of the enterprise, the project should clearly be treated as if the suitability of the site is in considerable doubt. That not only happens to be an accurate reflection of the technical situation at present. It is also a realistic depiction of the regulatory situation, since any repository design would have to conform to EPA standards which do not yet exist.

As a final indication of the risks of the course upon which DOE and Congress have set the country, consider the calculations which the National Academy Panel made in 1983 of the Yucca Mountain site. The Panel attempted to calculate the performance of various candidates sites and geologic media, in light of the proposed EPA and NRC standards, and its own individual dose standard.

Under pessimistic assumptions about the releases from the Yucca Mountain repository, the Panel's calculations indicate that individual doses from neptunium, via consumption of groundwater, could be enormous, as shown in the estimates for reprocessed wastes in Figure 5. The annual doses could be on the order of 20 sieverts, or 2,000 rem. This is four thousand times the maximum allowable exposure from all sources.

With less pessimistic assumptions about transport and retention of radionuclides in the repository, the Panel calculated that the Yucca Mountain site would meet the EPA standard which has now been invalidated by the courts, but that it would not meet the more reasonable standard set by the Panel itself by factors of 10 to 1,000. This means that the annual individual dose from repository operation could amount to many times the allowable standard for exposure from all sources. Figure 6 shows the Panel's calculations for this less pessimistic case, again for reprocessed waste.

These calculations point up in one stroke the essential deficiencies of the now-defunct EPA standards, and the potential risks in selecting the Yucca Mountain site alone for characterization. The National Academy Panel also noted that the

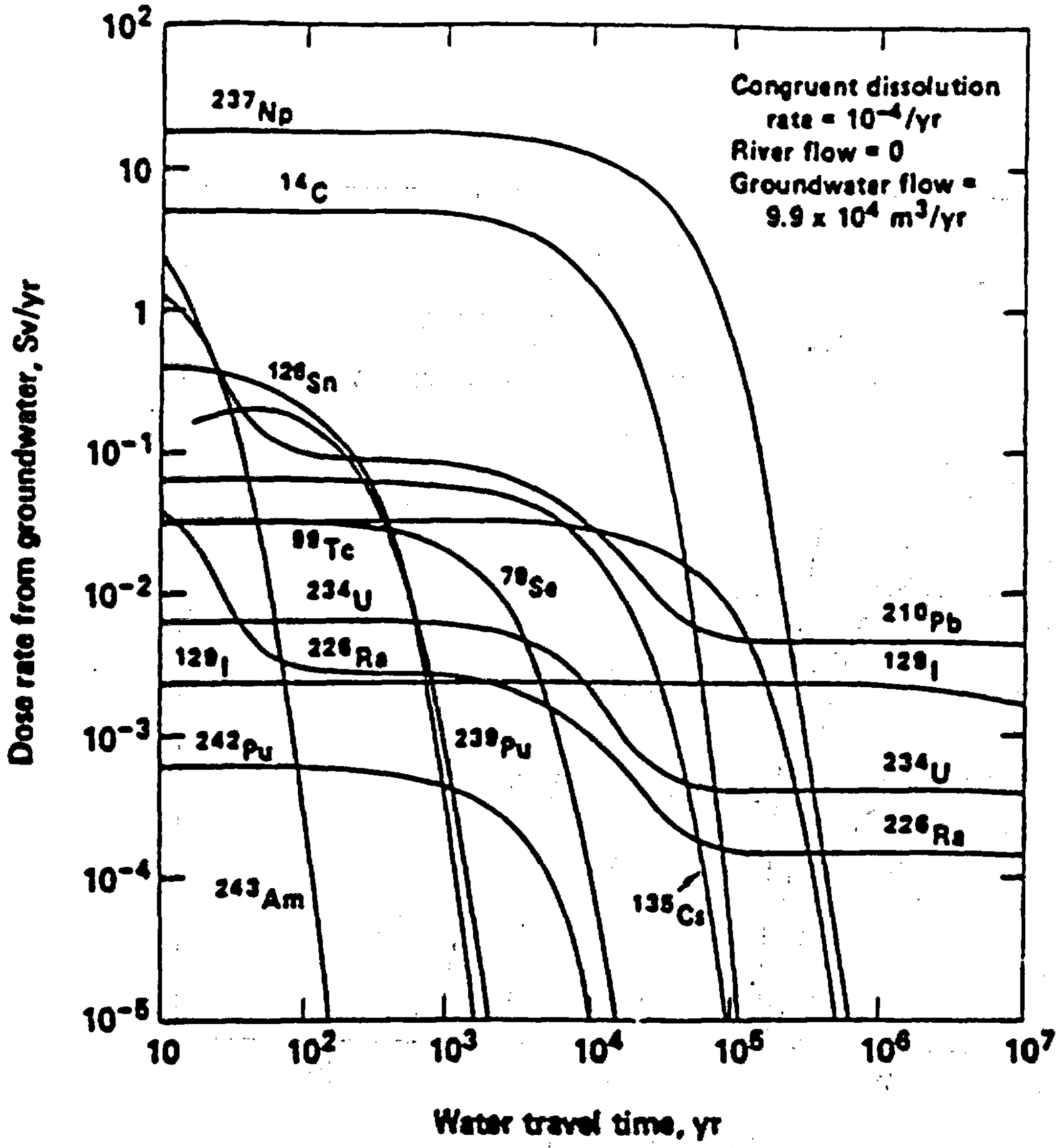

Figure 5. Individual radiation dose as a function of water travel time in tuff: reprocessing waste from 10^5 Mg uranium fuel, congruent dissolution, no dispersion.

Source: NAS, 1983.

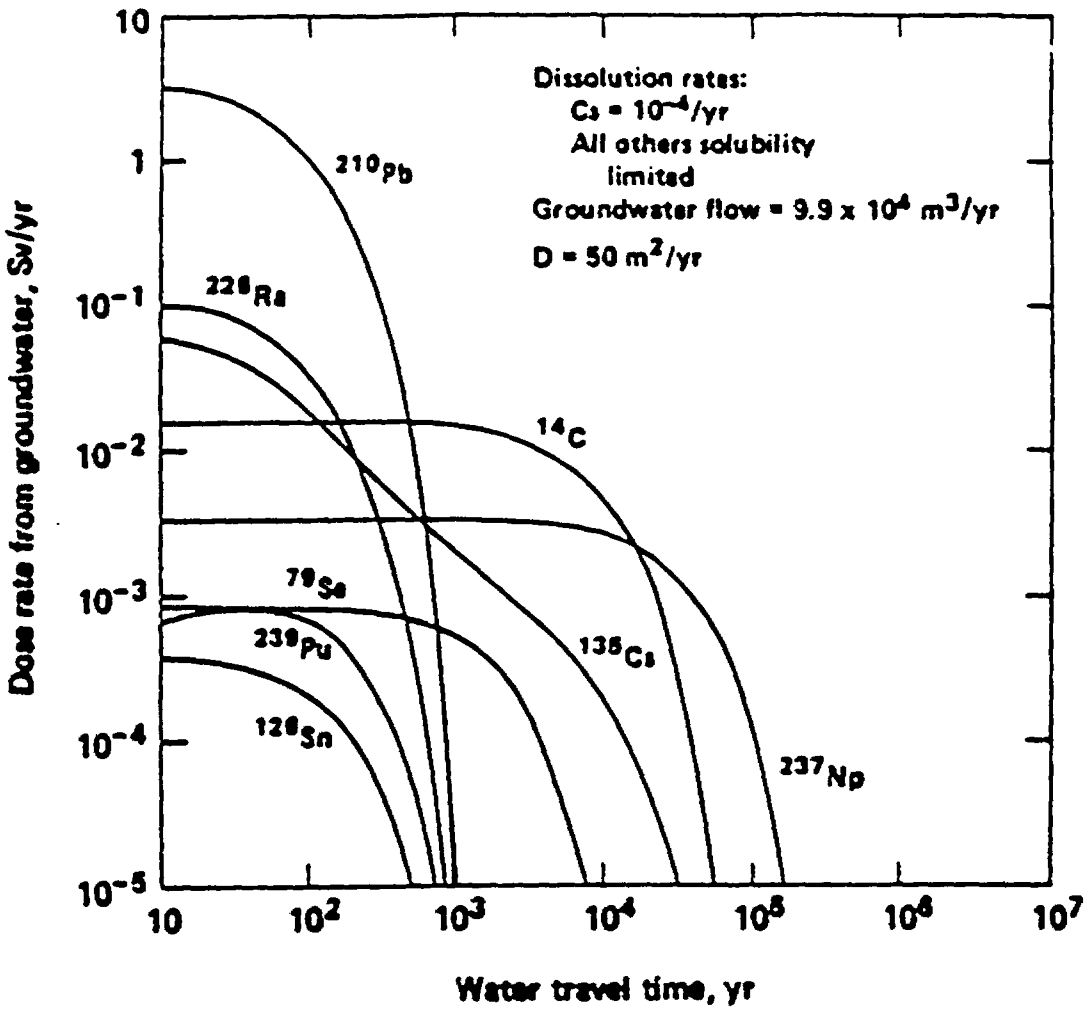

Figure 6. Individual radiation dose as a function of water travel time in tuff: reprocessing waste from 10^5 uranium fuel, solubility-limited dissolution.

Source: NAS, 1983.

risks from contaminated groundwater were higher in Nevada than at most other sites:

> "...it seems that any normal and continuing use of the potentially contaminated groundwater from a site in **saturated or unsaturated tuff** could present a problem, if the flow rates for contaminated groundwater are anywhere near those adopted in this study. The absence of flowing surface water in this region presents a greater incentive to use groundwater than for sites in less arid regions. For the long-term future considered here, the present wells are not significant as definite locations of future use of potentially contaminated groundwater, but they are significant in that **they show some likelihood of future human use of groundwater in this general area. Therefore we attach greater significance to the calculated groundwater doses for the tuff site than for sites in less arid regions."**[51] (emphasis added.)

Climate change, both natural and induced by human activities could complicate the picture further. The great controversies and debates surrounding average global effects of human activities show the limitations of our present understanding of the subject. To predict local effects (for an area the size of southern Nevada) of global climatic change with any confidence appears at present beyond our capabilities. Considerable work needs to be done before estimates of local climatic changes can be made with enough confidence to have some meaning for assessing repository performance.

B. THE RISKS OF SEQUENTIAL CHARACTERIZATION

The 1982 Nuclear Waste Policy Act mandated the simultaneous investigation of a number of sites with the eventual selection of two repository sites for construction. One site was to be in the West or Southwest and one in the East. There was more than political balance to this idea. A diversity of rock types was to be considered and characterized, so that the chances of the best possible isolation would be increased. Two repositories, rather than just one, would also reduce transportation of highly radioactive wastes correspondingly decreasing the risks of a serious accident.

By 1987, the manner in which the site selection and attendant process was conducted had led the process into an impasse. It was clear that the Act would have to be amended. But the 1987 revision of the Nuclear Waste Policy Act put the process on an even more risky course. Congress mandated that essentially all resources for site characterization be devoted to a single site: Yucca Mountain in Nevada.

We have detailed above how this decision was based on a tenuous assumption, which was being questioned by at least one internal DOE report, even before Congress passed the 1987 Amendment. Ignoring or suppressing data and analysis can not change the reality in the ground. If the site is in reality vulnerable to a rise in the water table up to the repository level -- then hundreds of millions or even billions of dollars will have been lost. Even more important, public confidence, already low from the considerable battering it has taken since the Lyons, Kansas fiasco, would sink even further, and local opposition will become even more determined.

These are not mere conjectures. Sequential characterization, also known as putting all your eggs in one basket, has a sorry history both in this country and abroad. In the context of the problems that Nevada faces, exacerbated by DOE management and methods, we summarize here the record of sequential characterization.

The search for a repository began in earnest in 1970. The experimental Salt Vault Project was designed to investigate the waste isolation properties of salt at an abandoned mine site near Lyons, Kansas. The site was not initially selected as a repository but only for experimentation. However, the need to find a place to put military wastes made politically urgent by a 1969 fire at a nuclear weapons plant at Rocky Flats, Colorado. Thereupon, the Atomic Energy Commission (AEC), DOE's predecessor agency, announced that the Lyons site would be used as a repository.[52]

Despite indications of problems, the AEC opined that the site was among the best in the country. By the time the affair was closed in late 1971, the site was found to have dozens of holes from previous mining and oil and gas drilling. It was, in the words of a Kansas geologist, "a bit like a piece of Swiss cheese". Indeed, a Kansas study concluded it was the "poorest candidate" of the eight areas considered in the general region.[53]

AEC was also checkmated in Michigan, when it tried to explore the state without getting a permit from the state government. There ensued the interlude in sequential characterization, during which the DOE cast a wide net, but without adequate preliminary study or preparation, and identified a number of salt sites. In addition, the Nevada Test Site area and the Hanford Site were thrown into the mix, more because they were on land controlled by the federal government than for technical considerations.

These initial missteps, and the apparent urgency lent to the waste problem by the 1976 California law barring construction of new reactors until safe disposal of waste is demonstrated, led up to the Nuclear Waste Policy Act of 1982. The subsequent fumbling of the effort to select several sites for characterization is well known, and we have described some of its features above. This led to the 1987 Amendment to the Nuclear Waste Policy Act and back to sequential characterization, with all its vulnerabilities.

The effort to deal with transuranic wastes from the nuclear weapons production program (the initial reason for investigating the Lyons, Kansas site) has followed a similar path. After its failure at Lyons, the site chosen for investigation for these wastes was near Carlsbad Caverns in New Mexico. The project was called the Waste Isolation Pilot Plant (WIPP). Again, there were warnings of possible brine pockets and intrusion of water, of potash deposits, and other problems. Moreover, DOE's plan for WIPP made provision for only 19 percent of the transuranic waste, and, according to a General Accounting Office evaluation, was "silent" regarding the other 81 percent.[54]

Yet the effort went ahead, with a confident schedule. Again, the approach was not one of scientific study with an uncertain outcome; rather the DOE proceeded to make promises to the governors of both Colorado and Idaho that transuranic wastes would be removed from their states and sent to the WIPP site by specific dates. There have been many deadlines, all of them missed. Finally, in 1988, the fact that water was seeping into the area where the waste was to be stored became public knowledge through Congressional hearings. There have been further technical complications since. Despite this, DOE continues to make promises about removing the wastes from Rocky Flats and from the Idaho National Engineering Laboratory to the WIPP site. After considerable expenditure, the effort is again in a technical and political crisis. There is now no definite, realistic date in sight for opening the site to receive waste.

Similar pressures to narrow the search to one site prevailed in West Germany, where, despite warnings from independent geologists, the search was narrowed to a salt dome near Gorleben, close to the East German border. It had tragic results. A worker was killed in accident in 1987, possibly caused by the interaction of geological problems and construction techniques.[55] The work in West Germany is now at a standstill, with the future of the program in doubt, with public confidence at a low point.

In sum, the history of sequential characterization is not a happy one. Generally, **it has resulted in sequential failures**. The problem is exacerbated at the hands of an agency like the DOE, which has shown a real resistance to learning lessons from its own history of failed efforts to create a viable program for long-term nuclear waste management.

CHAPTER 6

ASSESSMENT OF DOE PERFORMANCE

Coming to a tenable hypothesis about the functioning of an entire governmental agency is, admittedly, a difficult matter. But the importance of dealing with highly radioactive wastes in a manner that will protect the health of future generations is so critical that we must make such an evaluation. This will assist us in determining whether the institutional arrangements governing the disposal of these wastes are at all compatible with the gravity of the task and a sound program to accomplish it.

The Department of Energy has compiled an astonishing record of scientifically unsound and technically incompetent studies from Maine to Washington, from Texas to Wisconsin. The pattern is so clear and consistent and has persisted in so many of its efforts for so long that it appears to involve considerably more than the familiar questions of competence and integrity which might be remedied by replacing some personnel. Indeed, at the level of technical personnel, the DOE undoubtedly has many well-qualified and competent people.

Moreover, there is a pattern of ignoring adverse data and information. As we have shown in Chapters 4 and 5, this has happened even though the importance of such adverse data and information has been directly and repeatedly pointed out to DOE, by its own personnel, by the National Academy of Sciences, by other governmental and non-governmental scientists and scientific bodies, by the NRC, and by the affected States and Indian tribes.

The pattern of DOE site selection points to the conclusion that DOE is always confident that, no matter where it decides to sink a hole, no matter what the methodology, no matter what the adverse evidence, that it will succeed in building a repository at that place and disposing off the wastes there. This pattern is not consonant with the need to incorporate concerns for long-term consequences into institutional decisions involving nuclear waste.

The evidence for this goes far back into DOE's institutional history. For example, the AEC, DOE's progenitor, opined that the Lyons, Kansas site was one of the best in the country, once political pressures appeared to point to a quick decision on a site. Such a statement was made despite the fact that the AEC had not intended the site as a permanent disposal site, but only a place for investigating the properties of salt as a disposal medium. At the conclusion of the brief investigation, with the scientific insights coming largely from those outside the AEC, the site was found to be the poorest in the area, to say nothing of the entire country. In its haste and political expediency, the AEC lost a site it had had for experimentation. It also lost a good deal of credibility.

It has not been helped by DOE's subsequent efforts. In every case, it has believed that repository characterization or construction could proceed on short order, while ignoring the real difficulties and problem areas. In every case regulatory bodies, independent scientists, states, Indian tribes and concerned citizens have been able to point out immense flaws in the method and in the sites themselves.

DOE has dealt with the intense scrutiny it received during the comment periods for the reports it filed under the Nuclear Waste Policy Act of 1982 with a kind of long-suffering stoicism, apparently convinced that its initial decisions were correct whatever anyone might say.

Throughout the country, governmental officials and citizens have noted that the DOE did hold hearings, and listen to comments. Sometimes it even prepared responses. But DOE did not take them into account seriously enough to allow them to affect its decision-making on site selection. We note the comments of the Executive Director of the Wisconsin Radioactive Waste Board as one example:

> "For the most part, DOE appears to believe that compliance with the consultation provisions of the Act simply means soliciting state comments, and not actually considering those comments and revising documents where appropriate."[56]

Indeed, DOE's premise in ignoring much of the availabl^ data, information, and analyses appears to have been that states, Indian tribes and citizens would somehow not become aware of it, if the DOE ignored it. Further, many of its investigations appear to have been designed so as to not-find out information crucial to selecting good sites or to characterizing them properly. We have already cited several examples regarding this in Chapters 4 and 5. We will illustrate here how this was actually built into DOE's site screening methodology.

Site screening for the second repository was done by holding a series of workshops in which participants were asked to assign weights to screening variables according to their opinion of the importance of those factors. In any preliminary effort involving a complex subject, there is bound to be a dearth of information about many variables. As I noted in April 1986 at a local hearing on the second round sites:

> "DOE instructed workshop participants to assign zero weight to screening variables which were either 'unimportant' or 'judged to be poorly measured'. This places poorly measured variables on a par with unimportant ones. Its effect is to dismiss poorly measured variables as unimportant. This is scientifically and technically wrong. The importance of variables about which there is considerable ignorance can only be discovered by removing the ignorance, not by removing the variables from consideration."[57]

The Orwellian language cited in Chapter 4 in connection with the Hanford Performance Assessment, is only one expression of a larger logical and philosophical confusion within the Agency, perhaps brought on by an intense underlying desire to help the electric utilities get rid of spent fuel from reactor sites and to get on with nuclear weapons production with minimum attention to the attendant environmental costs and problems.

The facts of DOE's performance point rather clearly towards an institutionalization of ignorance about those aspects of site selection and characterization which might reveal that any site which DOE chooses to study might wind up being a poor choice. This institutionalization does not appear to have been the product of any consistent decision-making process, but probably merely the result of making environmental concerns secondary to production goals. This has also been revealed by a series of difficulties in recent revelations about DOE nuclear weapons facilities.

This has happened despite the presence of many individuals with considerable technical skills within the DOE, some of whom have tried, from time to time to correct one or the other problem with DOE operations.

To institutionalize ignorance as a part of one's decision-making, as appears to have been the case with much of DOE's long-term waste management effort, is to seriously compromise science, to say the least. In the present case, with all the complexity and uniqueness and difficulty of the enterprise, only a complete commitment to scientific integrity and openness about the facts with the people is likely to lead to success in protecting future generations from radioactive harm.

The history of the Department of Energy indicates that it is not qualified for such a responsibility. It should not be the institutional vehicle for that commitment to the health of future generations.

PART II

ALTERNATIVES FOR LONG-TERM MANAGEMENT

CHAPTER 7

LONG-TERM MANAGEMENT ISSUES

A. OVERVIEW

A number of possible methods for the long-term management or disposal of highly-radioactive wastes have been considered over the years. Some of these have been for military wastes alone, such as direct injection of liquid wastes into rock formations. Most methods have been considered for application to highly radioactive wastes from both nuclear weapons production and civilian nuclear power.

This assumption that a common management method would be suitable to both sources of waste arose from a more fundamental assumption widely prevalent until the late 1970's -- that spent fuel from nuclear power plants would be reprocessed to recover uranium and plutonium. Since irradiated fuel from weapons plants must be reprocessed (as discussed in Chapter 2), the assumption about civilian reprocessing meant that the wastes from the both civilian and military applications would be similar in form and composition. Hence, the assumption of a common mode of long-term management was appropriate.

However, reprocessing civilian spent fuel at present or in the foreseeable future does not make sense from economic, environmental, or non-proliferation grounds (see below). In the U.S., most of the industry itself has given up on it, and the operative assumption is that civilian wastes must be managed and disposed off as spent fuel, in the fuel rods themselves, without attempting to extract uranium and plutonium from them. As a result, a long-term management program must consider the properties of two kinds of waste whose radiological and chemical properties are by no means identical, except, of course, in that both are highly radioactive and must be isolated from the human environment.

Military wastes are to be mixed with molten borosilicate glass and cast into large cylinders at the Savannah River Plant, with hot testing of the operation beginning in 1990, according to the current schedule. The design of the canister in which spent fuel will be encapsulated has not yet been finalized.

Besides geologic repositories, a number of approaches were considered and rejected for the disposal of these nuclear wastes. The evaluations were made during the 1970s, when geologic repositories were settled upon as the most promising approach for further development. Among the other methods considered were:

- disposal into holes drilled into the sea bed;
- disposal into holes in the Antarctic ice cap;
- disposal by shooting the wastes into space;
- transmutation of long-lived radionuclides into shorter half-life elements by various means.

The first three of these methods were rejected because of the great risks and uncertainties. For example, one has only to consider briefly the consequences of an accidental destruction of a rocket carrying spent fuel to reject the option. Similarly, disposal in the Antarctic ice cap and into the earth under the ocean are too risky and uncertain. We will not discuss these further.

We will discuss geologic disposal and transmutation in some more detail in this chapter.

B. GEOLOGIC REPOSITORY

Geologic disposal was the method of choice for pretty much all parties to the debate in the late 1970s and early 1980s, once it became apparent that there would be no commercial reprocessing of spent fuel in the U.S. in the foreseeable future.

Various time estimates, all too optimistic, have been put forward at various times by the Department of Energy. The estimate in the late 1970s was that a repository could be opened by 1985. DOE's current estimate today, based on the unlikely presumption that Nevada will turn out well <u>and</u> that there will be no further slips in the schedule, is for a repository to open in 2003 for the acceptance of spent fuel.

By the early 1980s it had become clear that many nuclear utilities would face the question of limits on storage capacity for spent fuel at the reactor site. Storing fuel at the site in pools of water, the current predominant method, is expensive, produces radioactive waste, and poses some dangers (See Chapter 8). Thus, utilities, especially those facing constraints on storage capacity, had a sense of urgency to get rid of the fuel. Interim storage depots at sites away from nuclear reactors (called AFRs) seemed to be one solution. Provision was made in the 1982 Nuclear Waste Policy Act for a single large Away-From-Reactor storage site, called Monitored Retrievable Storage (MRS).

The controversies over site selection and over transportation risks, which resulted in a delay of the repository schedule from 1998 envisioned in the 1982 Act to 2003 at present, have also raised further questions about the desirability and schedule for a Monitored Retrievable Storage. Under the 1987 amendment to the Nuclear Waste Policy Act, a special commission is to make recommendation about this question by November 1989.

The question has largely been rendered moot however, in that many or most nuclear utilities will have to make room for more spent fuel at the reactor sites. It also puts into question other aspects of the schedule for a repository. Let us review the matter of schedule, for it is of considerable importance to the development of a long-term strategy.

The prospect of getting rid of the spent fuel from the reactor sites was one of the main motives for utilities and nuclear reactor manufacturers to back the 1982 Nuclear Waste Policy Act. The lack of any solution to the problem of long-term nuclear waste management had long been seen as an impediment to the development of nuclear power, and to its acceptance by the public. This question was brought to a head by a citizens' initiative which moved the California legislature to action in 1976.

In the context of this initiative, the State of California enacted a law to similar effect. The law imposed a moratorium on further construction of nuclear reactors until the technology for disposing off nuclear waste had been demonstrated. Litigation followed when the state attempted to enforce the law. The state prevailed. While the eventual Supreme Court ruling did not come until 1983, the fact that the California Energy Commission had been able to stop a major nuclear power project in the late 1970s on the grounds of the non-availability of a means for disposing off nuclear waste created a major and urgent impetus for those with commercial interest in nuclear power towards some solution which would get the spent fuel off the reactor sites.

Whether this might mean a long-term solution or a mere transfer of responsibility to someone else -- that is to the Federal Government -- appears not to have been carefully addressed.

The enormous delays in the schedule of the 1982 Act have shown that this matter was not as urgent as had been claimed. In its June 1988 Draft Amendment to the Mission Plan, the Department of Energy has admitted that it will renege on its earlier assurance to take charge of the fuel by 1998:

> "The DOE has entered into contracts with the owners and generators of spent fuel....The contract provides for the DOE's acquisition of title to the spent fuel, transportation and subsequent disposal. Under the contract, these services are to be provided 'after the commencement of facility operations.' The DOE recognizes that, under current conditions, waste acceptance at a waste-management facility cannot begin in 1998; furthermore, the delay in the repository schedule and the linkages between that schedule and key milestones in the siting and construction of an MRS [Monitored Retrievable Storage] facility make it unlikely that the DOE will be able to start accepting waste significantly before 2003....Under the current conditions, the owners and generators of spent fuel will continue to be responsible for storing their spent fuel."[58]

Indeed, while acceptance before 2003 appears unlikely, it is quite possible that DOE may not be able to remove fuel from the reactor sites until well after that date. The State of Nevada in its comments on the Draft Amendment to the Mission Plan noted that the new schedule contains no provision for delays or surprises:

> "The schedule for repository development published in the DMPA [Draft Mission Plan Amendment] is yet a further compression, from past schedules, of the time period for technical information gathering during the site characterization period. It anticipates no surprises in the geologic system, something that never happens when significant geologic investigations are undertaken. An additional six months have now been eliminated from the beginning period of exploratory shaft excavation and DOE is already six months behind that schedule."[59]

Under these circumstances, the expansion of storage capacity at the reactor sites for a considerable number of reactors, if not the majority of them appears to be a practical necessity for nuclear utilities. To rely on the DOE to take charge of the spent fuel even in 2003 would be speculative, given the history of serious delays, the considerable uncertainties involved in the program, and the possibility that Nevada, the only site being characterized, may turn out to have flaws serious enough to make it unacceptable as a repository.

In sum, one aspect of the problem of urgency has essentially been resolved: the DOE cannot accept any spent fuel for fifteen years or more and many or most nuclear utilities will have to build new storage capacity on site.

Figure 7 shows DOE's projection for the number of reactor sites at which additional storage will be required if it does start accepting spent fuel in 2003. It is evident that even with an optimistic schedule which does not allow for any further delays, most nuclear utilities will have to build additional storage capacity.

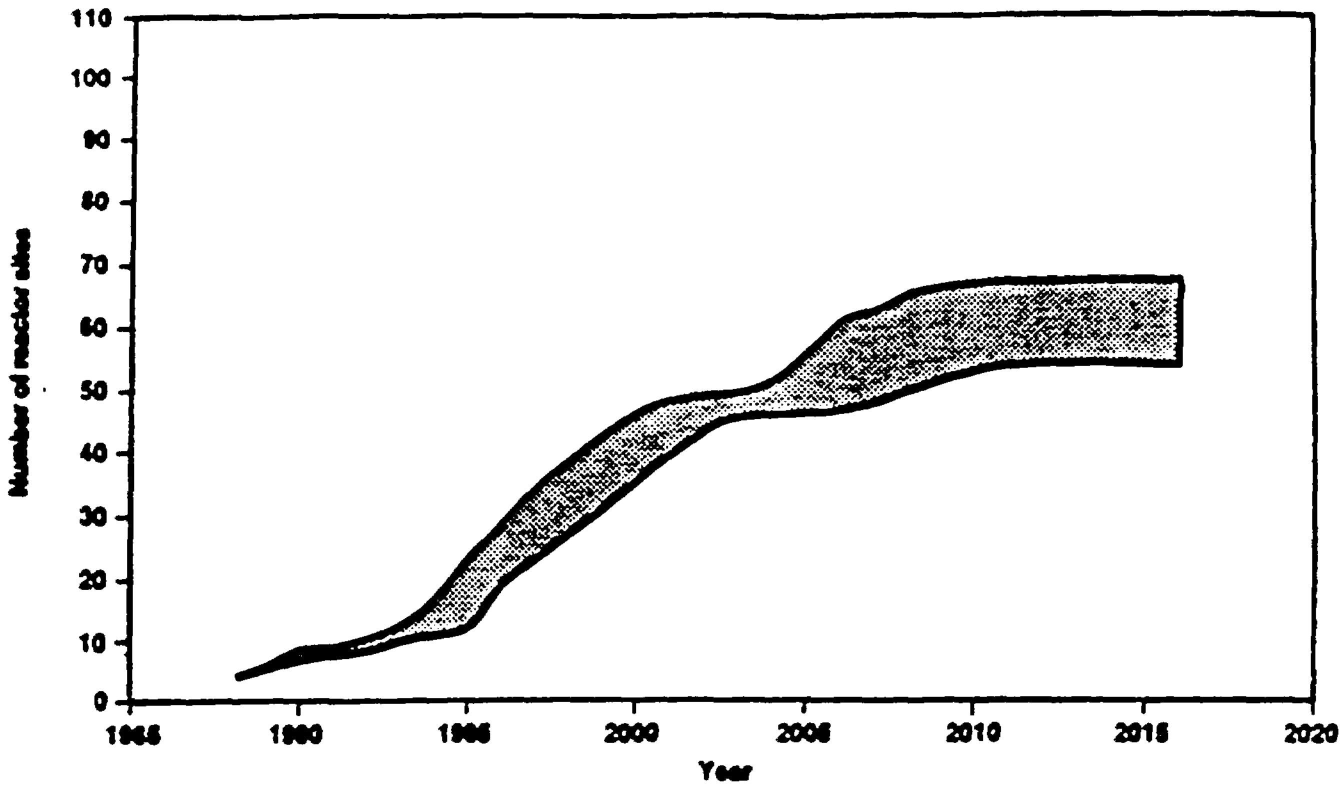

Figure 7. Number of reactor sites with additional-storage requirements with the reference spent-fuel acceptance case (repository starting in 2003).

Source: DOE/RW-0196

Another aspect of the urgency of the problem, generally given more importance by the environmental and arms control advocates has had to with reprocessing.

C. REPROCESSING

Reprocessing is a necessary part of the production of those nuclear weapons containing plutonium -- a category which today includes most of the weapons in the U.S. arsenal. (Nuclear weapons can also be made with enriched uranium, like the bomb that was dropped on Hiroshima. Hydrogen bombs contain a plutonium trigger.) Since spent fuel from civilian nuclear reactors also contains plutonium, its recovery has been an important consideration in policy-making relating to both nuclear power and nuclear weapons. Further, plutonium-239 is a product of the irradiation of uranium-238 with neutrons. U-238 by itself is not a fissionable material and thus useless for energy production directly. The prospect that the plutonium made from U-238 could be greater than the fissionable fuel used up in energy production seemed to be a theoretically very attractive proposition to the proponents of breeder reactors.

Breeder reactors are as yet far from commercialization, plagued by safety, technical, security, and cost problems. Indeed, in the U.S., the technology has been shelved as an option for nuclear power production. Further, reprocessing turned out to be far more expensive than its proponents imagined. The assumption that a technology which was in use in secret DOE military installations, where budgets and safety concerns were secondary to production, could be easily and economically used in civilian industry turned out to be untenable.

While reprocessing has turned out be far more costly and polluting than imagined, the demand for uranium turned out to be far less than forecast. The combination of these two facts makes it much cheaper to mine uranium than to use uranium and plutonium from reprocessing plants. Since there are both U.S. and foreign producers of uranium, there is little prospect of a change in that conclusion.

Finally, since it is the objective of reprocessing to recover plutonium for nuclear weapons production, this technology has been opposed by many who otherwise support nuclear power on grounds that if the U.S. does it, it will encourage other countries with civilian nuclear power plants to do it too, increasing the risk of nuclear weapons proliferation considerably.

It was on this last ground more than any other that President Carter banned reprocessing in the U.S. in 1977. While the Reagan administration tried hard to revive reprocessing, asking private industry to take up the challenge with some subsidies from government. The costs and risks being what they were, there were no takers.

A repository for spent fuel appeared to arms control advocates to be a good permanent solution to the problem of reprocessing, since once the spent fuel would be buried, it would be very costly and difficult to dig it up for reprocessing. This would effectively end any remote hopes that proponents of a breeder-reactor-based plutonium economy might entertain for recovering the large quantity of plutonium in spent fuel (about 9 kilograms per ton of spent fuel irradiated for 30,000 megawatt-days).

However, there is not going to be a repository any time soon. If anything, the prospect is greater that the Federal government may decide to take charge of the fuel from the utilities and build a Monitored Retrievable Storage facility. At such a facility, the presence of a large quantity of spent fuel would provide much more of a temptation for reprocessing, with all its environmental, economic, health, and security risks.

In sum, events have shown that the Nuclear Waste Policy Act and the social decision it appeared to embody to put spent fuel into a repository have not affected the prognosis for reprocessing. The continued lack of interest in reprocessing reflects the broad consensus against it arising from its considerable risks.

This analysis shows that declarations of the "urgency" of the problem are belied by the actual slow pace of the solution, made more slow by the bungling and fumbling of the DOE. Further, so far as reprocessing is concerned, the NRC requirement of retrievability for 50 years to overcome some of the uncertainty in repository performance, ensures that spent fuel will remain available for considerable periods for reprocessing even if a repository does get built on the present schedule.

On close examination, the argument that building a repository is "urgent" is without merit. Moreover, this false urgency is compromising long-term safety and health, in that there is less time for thorough investigations, pressure to accept less than the best possible site, and a lot of room for politics to play a much bigger role than it should, relative to technical considerations.

Further, a rush to build either a repository or a Monitored Retrievable Storage facility will increase transportation risks, far beyond those of a more measured and carefully paced program.

D. TRANSMUTATION

The nuclear reactions which occur in a reactor result in the transmutation of uranium-235 into fission products, and of uranium-238 into plutonium and other transuranic elements. Thus the question has arisen whether the principle of transmutation by nuclear reactions could also not be applied to nuclear wastes.

A number of different concepts have been considered over the years, and rejected as too costly or impractical. Generally, transmutation has been considered in the context of promoting nuclear power. In particular, the role of transmutation has usually been considered in the context of reprocessing spent nuclear fuel, combined with light water reactors, with breeder reactors, or both.

For example, plutonium-239, which is produced in reactors by neutron irradiation of uranium-238, has a half-life of 24,500 years, much longer than most fission products. It is also a fissile material which can be split by irradiation with neutrons to yield energy. Thus, its use in a nuclear reactors, either of the present variety or in breeder reactors, has sometimes been considered as a method of transmutation. One difficulty, however, is that in each round more plutonium and more fission products are produced. This includes the production of very long-lived fission products such as iodine-129, technetium-99, and cesium-135, whose inventories would grow considerably as a result.

Nuclear reactor based technologies also require the use of reprocessing, whose serious disadvantages from the economic, security, and environmental standpoint have been briefly discussed above and extensively discussed in the literature. Further, no U.S. utility has ordered a nuclear power plant for over a decade, and dozens have been cancelled. Finally, the breeder reactor program has been scrapped as risky and uneconomic. In sum, the arguments against any waste management approach that involves reprocessing are overwhelming and decisive.

Meyer Steinberg and others at the Brookhaven National Laboratory have advocated an approach to transmutation that adds further elements of complexity and cost. They suggest the use of linear accelerators to produce plutonium for light water reactors. They would use a reprocessing technique which would remove only short lived fission-products and allow long-lived fission products to remain behind with the fuel, or, as in the case of krypton-85, to be released to the atmosphere.[60]

This method might produce some advantages from the point of view of non-proliferation, since it would leave long-lived fission products in with the fuel. Such fuel could not be used to make nuclear weapons without further processing. By the same token, long-lived fission products would continue to accumulate, passing through nuclear power plants and reprocessing plants again and again, increasing the dangers in case of accidents.

The approach would add three very costly elements to the already costly light water reactor based nuclear power production system. These elements are: reprocessing, a "spallator" which is a combination of a nuclear reactor with an accelerator, and a fuel fabrication facility which would be much more radioactive and dangerous than today's facilities, since it would handle fuel containing plutonium as well as cesium-137 and strontium-90. Each of these elements could have costs of the same order of magnitude as current large nuclear power plants. Given the emerging consensus that, if further development of nuclear technology is to take place, it should be in the direction of modular, relatively small, meltdown-proof reactors, the approach advocated by Steinberg and his associates is inappropriate even from relatively narrow point of view of the financial requirements of electric utilities.[61]

Another approach to transmutation involves the use of high-energy gamma rays. High energy gamma rays are so-called because they have a large amount of energy per quantum, or photon. Irradiation of elements by gamma rays with photons can induce various nuclear reactions in them. These reactions are called photonuclear reactions. They result in the transmutation of the irradiated elements.[62]

High energy photons produce different reactions in different elements. In the relatively light ones, they can knock out a neutron; in heavier elements they can knock out two neutrons; in yet heavier elements like plutonium-239, they can induce fission, yielding the usual large array of fission products, most of them with short half-lives.

Each element from oxygen on up in the periodic table appears to respond with a high probability of photonuclear reactions to gamma rays within a specific range of photon energies. This range is called the "grand resonance region" because the probabilities of photonuclear reactions are especially high within it. The energy of these photons is usually measured in million electron volts (MeV). The energy at which the maximum probability of photonuclear reactions occurs for oxygen is 24 MeV. Heavy elements respond with highest probabilities to lower energy photons. The peak for bismuth-209, for instance, is 13 MeV.[63]

Thus, it would appear possible to select gamma rays of particular energies to produce photonuclear reactions in targeted elements. Unfortunately, the resonant peaks of phototransmutation probabilities for various elements are not sharp, so that it is not possible to focus the energy of a gamma ray beam on a single radionuclide, while excluding the excitation of photonuclear reactions in other elements.

Phototransmutation would be relevant only to very long-lived radionuclides, both fission products like cesium-135 (half-life, 2.3 million years), iodine-129 (half-life, 16 million years), and alpha-radiation emitters, like plutonium-239 (half-life, 24,400 years). In addition, we should also consider those radionuclides whose decay products are long-lived radionuclides. For example, americium-241 has a half life of 433 years, so that its direct radiation effects stretch over a few thousand years. However, it decays into neptunium-237, with a half-life of over 2 million years. As another complication, a relatively short lived isotope of plutonium, Pu-241, half-life 14.4 years decays by the emission of electrons (beta radiation) into americium-241, which in turn yields the long-lived neptunium-237. Thus, in order to avoid a very substantial build up of neptunium-237, it is important to investigate the potential of transmuting both americium-241 and plutonium-241.

Another very important consideration would be to induce photofission in the plutonium-239 in spent fuel. Apart from long-term environmental considerations, this could resolve the concern that long-term storage of spent fuel could lead some day to reprocessing and the use of plutonium for nuclear weapons production. Indeed, given that storage of spent fuel for extended periods is now inevitable, this might be a way of resolving the non-proliferation concerns in the next couple of decades.

Table 2 shows the radionuclides which might, in theory, be dealt with by transmutation. Some radionuclides with relatively short half-lives which decay into long-lived ones are also shown.

TABLE 2

RADIONUCLIDES WITH POTENTIAL FOR CONTRIBUTING TO RELATIVELY LARGE LONG-TERM DOSES

	RADIONUCLIDE	HALF-LIFE YEARS	NOTES
1.	carbon-14	5,730	
2.	selenium-79	65,000	
3.	technetium-99	214,000	
4.	iodine-129	16 million	
5.	cesium-135	3 million	
6.	neptunium-237	2.14 million	
7.	uranium-234	245,000	decays into Ra-226
8.	plutonium-238	88	decays into U-234
9.	plutonium-239	24,500	
10.	plutonium-241	14	decays into Am-241
11.	americium-241	433	decays into Np-237

One complication which needs to be addressed carefully is the complex nuclear reactions which will take place among the heavy elements which are likely to contribute substantially to the long-term doses. These elements decay into other radioactive elements, as discussed above. However, under the action of gamma rays in the resonant region for photonuclear reactions, the radionuclide composition of the spent fuel might change substantially in ways which might increase problems in some areas. Thus, knocking out a neutron from plutonium-238 yields plutonium-237, which decays into neptunium-237, one of the troublesome elements for long-term doses. However, the normal decay chain of plutonium-238 yields radium-226, which is also a troublesome element.

Another limitation of phototransmutation is that after a certain proportion of a particular element has been transmuted, it becomes more and more costly to deal with the remaining fractions. Thus, considerable quantities of particular radionuclide might remain, even if other problems can be solved. Phototransmutation can also transform non-radioactive elements into radioactive ones. These would generally have short half-lives, but the question needs some attention and study.

The Energy Research and Development Administration briefly considered phototransmutation in its 1974 evaluation of alternative methods of long-term waste management, done for it by Battelle Northwest Research Laboratories. Its investigation was brief because it concluded that the amount of energy needed to transmute the troublesome radionuclides would exceed the energy generated in the nuclear reactor. In that case the nuclear fuel cycle would have a negative energy balance, making it technically absurd to continue nuclear power generation..[64]

This is a powerful argument against transmutation. It appears to be valid for photonuclear reactions in the grand resonance region, particularly as it would be difficult to direct the energy to the required reactions alone. Since plutonium, and the other radionuclides of interest constitute only a small fraction of the spent fuel, most of the 10 to 20 MeV photons would be directed at atoms other than the ones of interest. Thus energy argument against transmutation is difficult to overcome, unless sharper resonances at lower energies exist.[65]

These limitations indicate that transmutation of any kind is unlikely to play a significant role in long-term waste management. The cost, dangers, complexity, and likely huge environmental impact of the technology for the very modest role (at best) it might theoretically have in reducing the long-term dangers of radioactive waste make it a poor choice for investment of resources which might be better concentrated on the study of container design, geology, and climate change.

E. TRANSPORTATION

The transportation of highly radioactive nuclear wastes presents substantial risks in the event of a serious accident. If there is loss of containment and radionuclides are released, there could be considerable damage to health, property and the environment.

The health and environmental risks of transportation depend on numerous interrelated factors such as the design of the transportation containers (called casks), the routes which are taken, the training of the personnel, and so on. We will not address these issues in detail, but will refer the reader to a study by Marvin Resnikoff on the subject published by the Council on Economic Priorities, where further references may be found.[66]

The issues we will consider here are those that pertain to the intersection of transportation risk and long-term waste management. These are as follows:

1. The age of the fuel when it is transported;
2. The nature of the container in which spent fuel is transported;
3. The total amount of transportation, in ton-miles, required by any particular long-term management approach.

The age of the fuel when it is transported is one of the principal determinants of the quantity of radionuclides that would be released in case of a loss of containment in a transportation accident. As discussed earlier, Figures 1 and 2 in Chapter 2, show that radioactivity in fuel per ton of heavy metal declines from almost 2 million curies per ton for fuel which is one year old measured from the time of discharge from the reactor, to 300,000 curies per ton at ten years, to 30,000 curies at the end of 100 years.

At one year after discharge from the reactor, the intensely radioactive, short-lived radionuclides like iodine-131 have decayed away. However, a considerable amount of other dangerous radioactive materials will still remain. Four are notable among them: krypton-85, with a half-life of 10.7 years; strontium-90 with a half-life of 28.8 years; cesium-137 with a half-life of 30.2 years, and plutonium-241, with a half-life of 14.4 years. (Of course, there are also the very long-lived radionuclides, which can only be dealt with by appropriate long-term management.)

If we exclude the very long-lived radionuclides for the moment, these four radionuclides present much or most of the risk in transportation accidents and any consequent releases. In view this, the amount of time spent fuel is stored must include their effect on transportation risks. This has been an issue which has been underestimated in DOE evaluations of health risks from repository operation.

The integrity of the container in case of accident is also a major issue. A 1984 report of the Council on Economic Priorities on Transportation concluded that transportation of spent fuel was unsafe, particularly as regards the design and fabrication of the cask:

> "...[W]e conclude that transportation [of spent fuel], as presently practiced, is unsafe. Shipping containers, called casks, are poorly designed and constructed. Because each holds a tremendous inventory of radioactivity, the casks now in use threaten accidents which, while unlikely, would be as serious as a meltdown at a nuclear reactor. Many more people and much more property could be affected by a cask accident than by a reactor meltdown, because a cask accident could occur in the midst of a populous city."[67]

The Resnikoff study, on the basis of national truck accident data, projected that the total expected number of accidents to the year 2000 involving spent fuel shipments to an Away-From-Reactor storage site (or Monitored Retrievable Storage site) in the Southeastern United States would be 27, while that to a site in the Northwest would be even higher -- 59, because of the longer average transport requirements.[68]

The transport of fuel to a surface storage facility in Nevada would be comparable to that for a Northwest storage site because, in both cases, most spent fuel would be shipped from nuclear reactors far to the east.

The Nuclear Regulatory Commission estimate of the costs of a severe accident involving the release of radioactivity due to a transportation accident is about $4 billion. According to the Resnikoff study, this represents a serious underestimate because of unrealistic assumptions about the ease of clean-up under urban conditions, ignoring persistent contamination or contamination inside buildings, etc. Resnikoff estimates property loss alone may be in the tens of billions of 1982 dollars, with realistic assumptions about an accident in New York City. In addition, there would be the costs of large numbers of cancers, litigation, etc.♣

Of course cask design has been continuing since 1984. There have been some promising developments, including the licensing by the NRC of Castor casks of West German design for on-site storage. These casks also appear to be better tested in terms of their crashworthiness than the ones discussed above.

However, DOE continues to have problems in the area of cask design, manufacture and performance. It has been using Type-B casks, which have not yet been licensed by the NRC. Since the NRC would not licence them, the DOE issued its own licenses and went ahead and used the casks. In a recent evaluation of 41 of these casks by Westinghouse, only 13 were found to have no safety related concerns. Of the rest, eight had "potentially significant safety related concerns" and 20 had "less significant safety related concerns".♣

The area of transportation cask design, like so many others, needs considerable further work. Extended on-site storage of fuel will not only reduce transportation risks because of the smaller inventory of radionuclides, it will also allow time to develop adequate transportation casks.

CHAPTER 8

ON-SITE STORAGE

A. SPENT FUEL POOLS

When spent fuel is discharged from a nuclear power reactor it is very hot. It continues to generate considerable heat due to the decay of fission products contained in it. At present, almost all this fuel is stored at the reactor sites, underwater in spent fuel pools. The water contains boron, a neutron absorbing element. This is needed to prevent an unintended criticality in the spent fuel storage pool. The water keeps the fuel cool, removing the heat of radioactive decay from the fuel rods. Physically, the situation in a spent fuel pool is similar to that in nuclear reactor which has been shut down.

Storing spent fuel in pools, the predominant present method, has some distinct disadvantages.

First, there is the possibility, even if remote, that a melt-down of fuel might occur in the unlikely event of a loss-of-coolant accident. This would be analogous to a loss-of-coolant accident in a reactor. some factors, particularly the lower content of dangerous short-lived radionuclides, like iodine-131, would tend to mitigate the consequences of such an accident. On the other hand, the larger quantity of spent fuel, as well as the absence of containment structures similar to reactors might make loss-of-coolant accidents more serious in heavily charged spent fuel pools.

Another disadvantage is that pumps must continually circulate the water both to remove the heat and to remove radioactivity and other impurities which get transferred to the water from the surface of the fuel rods. Thus, a considerable amount of low-level radioactive waste is produced, which adds to the cost and risk of nuclear waste management.

Finally, long-term storage underwater tends to corrode the fuel rods, raising the possibility of substantial leakage of radioactivity into the water. The management of leaky fuel rods is much more dangerous and difficult than rods whose cladding is intact.

In many ways, apart from the actual production of electrical power and all that is associated with it, many of the essential characteristics of spent fuel storage in pools are like fuel in a reactor itself, with the nuclear reaction shut down by borated water.

B. DRY STORAGE OPTIONS

Dry storage would overcome most of the difficulties of storage in spent fuel pools. Since dry storage facilities do not have water (by definition), there is no neutron moderation and no possibility of an accidental criticality. Further, the system does not continually accumulate low-level radioactive waste, since there is no water circulation, and, in most methods, no pumps for circulating any cooling gas.

However, the development of dry storage did not intensify until the last decade. It is only in the last four years that actual licensed facilities have operated in this country. Casks suitable for dry storage have been available for somewhat longer in West Germany.

Today, however, there are a number of options which have been demonstrated and one which has been licensed by the NRC and tested for about four years. The delay in the schedule for a repository has undoubtedly accelerated these developments. The options outlined in a recent survey by the DOE are[71]:

- o dry storage in metal casks;
- o dual purpose storage and transportation casks;
- o concrete dry storage casks;
- o horizontal concrete dry storage system;
- o modular vault dry storage system.

The NRC has licensed Virginia Power to operate a dry storage facility using Castor V/21 casks of West German design. The experience so far appears to be positive, and without major difficulties. Safety studies have been done on others.

The technology of dry storage in metal casks is modular, so that new capacity can be added only when it is needed, in contrast to spent fuel pools, where a large facility must be built at one time, and where lead time and attendant economic uncertainties can be considerable. Figure 8 shows a conceptual design of dry storage in metal casks.

There appears to be no impediment to expanding this form of storage at reactor sites. Careful monitoring should accompany such an expansion, since the technology is still relatively new. While there appear to be no major difficulties at present, such monitoring is needed to catch any unanticipated problems which might occur. It is important to note that dry storage on site does not allow one to get rid of spent fuel pools altogether. This is because the spent fuel is very hot at the time of discharge from the reactor and would damage or melt the dry casks. Therefore, storage under circulating water for at least twelve to eighteen months is essential. It is possible that future designs will be able to cut short the required period of underwater storage.

Several dry storage concepts are in various stages of development and licensing. Generally, passive dry storage, which does not require pumps to circulate air or other gases to cool the spent fuel, is the preferable approach from the point of view of reducing the risk of accidental radioactivity releases. Dry silo storage with natural convection has been demonstrated. However, in theory at least, completely enclosed storage in a closely monitored environment, with no exchange of gases between the inside and the outside, appears most likely to provide the best possible on-site storage option for reducing the risk of accidental releases.

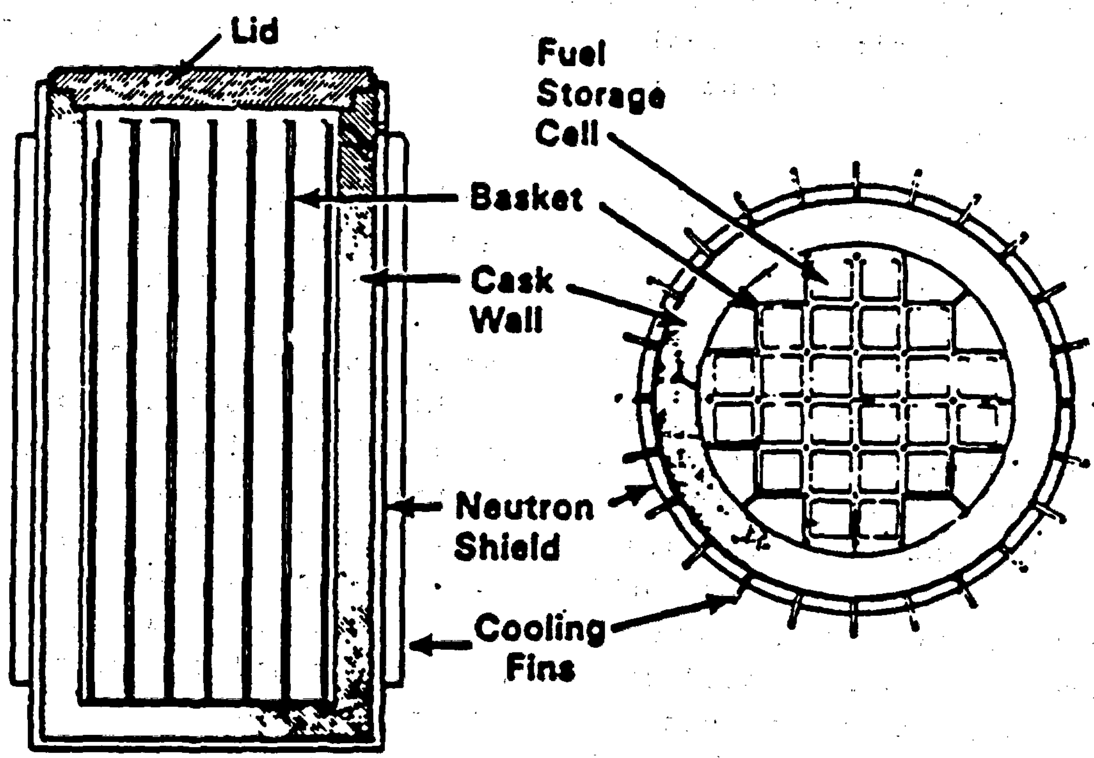

Figure 8. Conceptual design for a typical storage cask.

Source: DOE/RW-0196

C. SOME ECONOMIC CONSIDERATIONS

On-site storage is going to be a reality for most nuclear utilities in the coming decades, whatever the outcome of DOE's efforts in Nevada. It is also a reality that considerable amounts of low-level radioactive wastes are being generated at these same sites. Finally, the decommissioning of the reactors is going to present utilities with considerable costs and problems.

Since on-site storage must be built anyway, it is important to consider storage for an extended period up to 100 years. This could provide increased safety and economic advantages.

As already noted, on-site storage for up to 100 years would reduce transportation risks considerably, since most of the krypton-85, strontium-90, and cesium-137 would have decayed away. Extended storage would allow time for thorough study and development of waste forms and repositories. Most important, it would allow time for sufficient understanding of the geologic problem to reduce considerably the uncertainty involved in the kind of long-term predictions that are needed to ensure that the standards which are set for the protection of future generations from the radioactivity will have a reasonable chance of being met.

There would be costs for monitoring and for security at the site. However these are likely to be much more than offset by the decrease in decommissioning costs for the reactors and by a substantial reduction in the costs of low-level waste management. One estimate of the cost of monitoring and security for a reactor is approximately $70 million over 100 years, or $700,000 per year.[72]

A substantial proportion of decommissioning costs is related to the radioactivity at the site: the quantities of radioactive materials that must be handled, the intensity of the radiation field in work areas, the number of work areas with radioactive materials present, etc. Deferring decommissioning for extended periods would allow a reduction of this radiation related cost and also allow time for the development of safer and more economical methods for decommissioning.

Current estimates of decommissioning costs vary considerably. It has cost almost $100 million to decommission the relatively small Shippingport reactor near Pittsburgh. Yet, official estimates of decommissioning costs of much larger reactors are on the order of $100 million to $200 million. A more conservative estimate might be that decommissioning costs might be of the same order of magnitude as construction costs -- roughly $1,000 per KW. This amounts to $1 billion for a 1000 MW reactor.

Estimating the costs of decommissioning is beyond the scope of this paper. The issue here is the complementarity of on-site spent fuel storage with deferral of reactor dismantling. Assuming a range of $100 million to $1 billion per reactor for the sake of discussion, the total costs for decommissioning 100 reactors over the next several decades will be in the range of $10 billion to $100 billion. Any significant dent in these figures would produce large savings for utilities and ratepayers, while yielding many safety benefits.

Low-level waste management costs would also be substantially reduced. According to a European Nuclear Energy Agency report, the volume of wastes from decommissioning are expected to be "about the same order of magnitude as the volume of [low- and intermediate-level] wastes" during 25 years of the routine operation of a reactor. The NRC estimates that deferring dismantlement of the reactors for 50 years, the amount of material which would need to be managed as low-level waste would be reduced up to 90%.[73]

D. MILITARY HIGH-LEVEL WASTE

Most military high-level radioactive wastes are stored in liquid or sludge forms at the Savannah River Plant in South Carolina and at Hanford, Washington. Converting these wastes safely into solid forms suitable for on-site storage should be a very urgent priority. This is because the tank storage has had a considerable history of operating problems and leaks which have caused considerable pollution and aggravated both health risks and the costs of long-term management.[74]

The tanks also generate explosive gases, including hydrogen. In case of failure of ventilation systems these can cause explosions, particularly at Savannah River, with potentially disastrous consequences.[75]

As noted in Chapter 5, a plant tc mix the high-level waste with molten glass and cast it into solid form is being built at Savannah River. However, this waste form may not be compatible with the hydrogeology of the Yucca Mountain site, if it becomes saturated with water. It is therefore important to plan to store these glass cylinders on site for an extended period, until the issue can be resolved. This would also reduce the risks from strontium-90 and cesium-137 of any transportation accidents, since these are the principal long-lived fission products in terms of their radioactivity. Finally, cooling the glass cylinders for an extended period before disposal in a repository may considerably reduce the risk of disintegration of the glass from contact with water, and make it more compatible with a wider variety of geologic environments.

A plan to solidify the high-level wastes at Hanford needs to be urgently implemented. Such a plan should not only provide for on-site storage, but also take into account compatibility with the kinds of geologic media in which the waste may eventually be placed. The decision to glassify the Savannah River wastes is too far into the implementation stage to be changed. But at Hanford calcining (converting the wastes into a powder form for temporary, monitored storage on-site) should be carefully considered as an interim measure. This is because glassification is a final waste form, and this must be compatible with a repository location. Calcine powder, in contrast, is only a temporary waste form, which can be mixed not only with glass, but with other materials such as ceramics, or synthetic waste forms, which might provide better isolation properties and compatibility with a wider range of geologic environments.

The DOE plans to commingle glass cylinders predicted from military high-level wastes with civilian spent fuel. Yet, all of the money for site selection and site characterization under the Nuclear Waste Policy Act has come from the ratepayers of nuclear electric utilities. In other words, a tax on electricity ratepayers has been used to subsidize nuclear weapons production. As of October 1987 The Department of Energy had collected more than $3.4 billion from the ratepayers.[76] There is as yet no definite provision for any contribution from the weapons program.

While the total radioactivity in military waste will be smaller than that in civilian spent fuel, military waste might occupy a comparable volume in a civilian repository. The exact figures will depend on which wastes are consigned to the repository and the specific waste form which will be chosen for the wastes at Hanford and Idaho. In the interests of equity and sound management of the military program, it is important that an appropriate proportion of the costs of the long-term program recommended in this study come from the nuclear weapons production budget.

PART III

SYNTHESIS

CHAPTER 9

A LONG-TERM WASTE MANAGEMENT PLAN

A. OBJECTIVES OF LONG-TERM NUCLEAR WASTE MANAGEMENT

The primary goal of long-term waste management is quite easy to state: it should be to protect to the greatest possible extent the health of future generations from the dangers of highly radioactive waste. There are two other considerations as well. First, we must make the protection of the health of future generations consistent with minimizing risk to people who are now alive. Second, solutions must also be within some broad definition of affordability.

Long-term management of nuclear waste involves one aspect which is not found in many other issues: it must rely on predictions over enormous time periods, extending to millions of years. The uncertainty in such predictions is so great that efforts made with the best faith and with the best available technology may still miss the mark by considerable amounts. Complicating this picture further, is the lack of knowledge of future patterns of human settlements and resource requirements. If the past couple of hundred years are any guide, these patterns are likely to change drastically well before the dangers from radioactive waste have become definitively small compared to other risks, such as those from natural background radiation.

Given these realities, minimizing uncertainty itself takes on the aspect of a major goal, since we must not only make predictions about the consequences of our actions, we must be reasonably sure that the actual result will meet the standards that we have set.

It is very difficult to translate these statements of general goals into technical and institutional policies and standards. We have discussed the EPA and NRC standards in Chapter 3. These standards are inappropriate to the goals we have discussed above and should be rejected. They do not cover the requisite time periods. They may result in considerable damage to the health of maximally exposed individuals.

We have also discussed the approach recommended by the Waste Isolation Systems Panel of the National Academy of Sciences. This is to set a maximum permissible dose limit to an individual for all future times. The National Academy Panel advocated a lifetime average of 10 millirem per year, which is about 10% of natural background radiation.

We endorse the approach of the National Academy Panel, but not the actual figure that it chose for maximum exposure, which is rather high considering it would be from just one portion of the system of nuclear power and weapons production. The maximum permissible lifetime dose should be set with adequate consideration given to prenatal doses.

It is still necessary to translate this standard into adequate technical standards and regulations for the performance of the waste package and the geologic repository. The minimization of risk over the next several decades also needs to be considered since we must make that compatible with long-term protection of health and the environment. Finally, we also need to consider the institutional mechanisms by which these goals will be achieved, and the regulations enforced.

B. TECHNICAL ASPECTS

At present only two methods, which complement each other, of managing highly radioactive wastes over the long-term which appear to have significant promise of helping meet our goals for radioactive waste management: packaging of waste for long-term containment and geologic isolation.

Predictions of the performance of a repository face the considerable problem of the inadequacy of our knowledge, the great uncertainties of long-term predictions, and the relatively recent period in which sophisticated measurements have even become possible. Given these considerations, and the rather poor history of site selection, we cannot have reasonable confidence that we understand the geologic media well enough at present to protect future generations from the adverse consequences of our actions.

Another very important consideration is that technology for safe transportation needs to be considerably improved, considering the very large numbers of shipments of spent fuel and military high-level wastes that would be involved.

Thus, it appears premature to rush into repository selection and characterization, to say nothing of construction and operation at this stage. This is reinforced by the potential problems with glass as a waste form, with NRC regulations, and the absence of any EPA regulations to govern repository performance.

The fact that there is no particular urgency from a technical or safety standpoint for building a repository underscores the need to stop the present process which has been characterized by a series of poor technical and institutional decisions. The availability of at least one licensable option for dry storage of spent fuel on-site and the possibility of dry storage without any serious complications for solidified military wastes allows us the time to investigate the problem of long-term isolation with the time and resources it deserves.

As we have discussed, on-site storage for extended periods (on the order of 100 years) is also desirable from the point of view of minimizing transportation hazards from krypton-85, strontium-90, cesium-137, and plutonium-241, the principal radionuclides in spent fuel ten years after the fuel as been discharged from a nuclear power reactor.

Thus extended dry on-site storage is needed to:

- o resolve the problems and reduce the uncertainties associated with long-term management;

- o reduce the temperature of the waste, thereby reducing the possibility of early disintegration, enhancing safety and enabling a wider variety of canister designs and geologic media to be considered and also enabling a larger quantity of waste to be disposed off in a repository of a given volume;

- reduce substantially the hazards of nuclear waste transportation ;

- reduce the costs and dangers of decommissioning nuclear reactors, provided adequate monitoring and security is maintained;

The present process of site selection and characterization is too thoroughly compromised both technically and institutionally. It is essential to abandon it. The false sense of urgency which has pervaded the program needs to be abandoned by the utilities, by the federal government and by those who have felt that a law mandating a repository would somehow reduce the risks of nuclear weapons proliferation by eliminating the option of reprocessing. This last objective has clearly not been achieved by the present program. And as we have discussed, there is no urgency from the point of view of the nuclear utilities, because most of them will have to build on-site storage facilities anyway, because the federal government cannot accept the spent fuel from them until 2003 at the earliest.

The current stage of investigation for geologic repositories should consist of scientific research, involving theoretical, laboratory, and field studies. It is a phase in which engineering design of possible repositories should be studied not so much with the idea that the wastes will be put in any particular geologic environment, but to aid and help focus scientific efforts for eventual translation into designs for repositories, canisters, etc.

Considerable research is also needed on the design of the canisters into which spent fuel will be put for eventual disposal. The current NRC standards of 300 to 100 years of perfect containment and then allowing releases of one part in 100,000 per year are arbitrary and unrelated to consideration of long-term protection of health or to radionuclide composition of the wastes. (See Chapter 3.)

A spent fuel canister with a much longer design life would help reduce the reliance on geologic isolation. This would considerably reduce the uncertainties associated with prediction of the performance of the geologic medium itself. The Swedish approach to long-term waste management puts considerably more reliance on the performance of the waste canister as an isolation mechanism than the U.S. approach. As an ad hoc National Academy of Sciences Panel noted in 1984:

> "The Swedish plan differs from most others in its heavy reliance on engineered barriers, specifically thick-walled copper canisters to enclose the spent fuel rods, surrounded by buffers of compacted bentonite."[77]

The Swedish estimate for isolation which would be achieved by the specially designed canisters, made by the Swedish Corrosion Institute, was on the order of 1 million years. The National Academy review concluded that this estimate was "fully justified."[78]

The National Academy review also concluded that if the estimate of isolation achieved by the canister plus the bentonite overpack for at least 1 million years is sound, then "the other parts of the [Swedish] disposal plan are of secondary importance."[79]

Taking this approach could be vital to the success of geologic isolation, even if a particular geologic setting appears to provide for adequate isolation. Among the changes that are difficult to predict, indeed at present they are impossible to predict with confidence, are the local effects of global climatic change. These could be very severe indeed, even if global average temperature changes are relatively small. This adds an element of uncertainty to any geologic setting, and reinforces the need to reject the present NRC standards for waste package performance.

In brief, our recommendation is that the NRC regulation restricting the life of the canister to 1,000 years and the complete disintegration of the canister to 100,000 years should be scrapped. A program of research and development for canisters similar to the Swedish, preferably in collaboration with that program, should be undertaken. We must aim for performance of a million years or better.

Collaborative international efforts are desirable even beyond cooperation with the Swedish program, if only to avoid the repetition of costly mistakes. For instance, the tragic accident in West Germany which resulted from the politically expedient decision to proceed with sequential characterization should have given U.S. policy-makers pause. But the absence of a strong collaborative effort with scientific and technical integrity prevented the lessons from being learned. As another example, the some of the cask being considered for on-site storage are of West German design.

Our recommendation for the overall isolation system is that the isolation achieved by the canister and the repository should be accorded equal importance. It is likely that considerable uncertainties will persist -- though they will be very much reduced by a program of research and development that would last many decades. Thus the geologic isolation would be a back-up in case unanticipated processes changed the conditions in the repository and caused the canister to disintegrate much faster.

It is also vital that considerable resources be devoted to understanding geology, including all the relevant sub-disciplines. This should include a very substantial component of research into the basic science. Besides the evident fact that this would have considerable benefits in other areas of human endeavor, such as reducing casualties from earthquakes, the understanding of the geologic media and all the natural phenomena which occur in them is needed to model the ways in which radionuclides would be released from a repository and reach the human environment. Similarly, research on climate change as it might affect repository performance is also very important.

C. INSTITUTIONAL CONSIDERATIONS

The Department of Energy has repeatedly failed to do site selection and related activities with the scientific, technical and institutional integrity which is needed for a program with such serious implications for the health of future generations. DOE's principal emphasis has been on promoting nuclear power and in helping nuclear utilities to get rid of the spent fuel from power plant sites even at the cost of technical and scientific integrity. Likewise, its principal emphasis in the weapons program has been on weapons production, even at the cost of serious damage to the sites and of similarly compromised science.

Besides the evidence of institutionalized incompetence and ignorance which we have presented, and there is much more which we have omitted for brevity, there are several more reasons why the Department of Energy should be relieved of its responsibilities in the area of long-term management of nuclear wastes. First, DOE has got its hands full with the breakdown of the nuclear weapons complex, and the many urgent conflicts of cost, environmental clean-up, safety and national security which have followed that breakdown. Second, there appear to be considerable unresolved conflicts in DOE extending to the very top levels regarding how safety, cost, environmental, and security concerns can be reconciled, and if they cannot be, which of them should have top priority. These conflicts should not be allowed to compromise questions of long-term radioactive waste management.

Finally, and from a pragmatic point of view, once on-site storage for an extended period is accepted, there is no reason for the costly and complex bureaucracy which DOE has built up to continue to exist. DOE has built up this organization on the presumption that a repository characterization will soon begin and that repository construction will begin in a decade.

Our recommendation is to abandon the present flawed and utterly compromised and risky process in favor of an extended program of basic scientific study, of research and development. This means that a body much more dedicated to the scientific aspects of the matter -- an area in which the weaknesses of the DOE are most glaring -- should be constituted to direct and evaluate the progress of the program.

The research and development itself can be carried out at universities, government laboratories, and by industry under contract to government. Since the spent fuel and the military waste (in solidified form) will be stored on site, there will be no need for a new organization to attend to the task of waste management for the next many decades. The NRC should continue to be responsible for licensing any additional spent fuel facilities that might be needed at the reactor sites and for the licensing of dry-cask storage methods. The EPA, NRC and appropriate state-level agencies should be given authority to monitor and regulate waste solidification and storage at the weapons plants.

A new institutional mechanism is needed for the next few decades to manage the research and development of a long-term waste program centered on a canister research and development and on geologic repositories. This could consist of a body much more like the National Science Foundation in structure than the DOE waste program. Indeed, a new department in the National Science Foundation could coordinate and oversee the program.

Another option would be to create a new ad hoc government agency, with its Board of Directors selected from among appropriate federal agencies, such as the EPA, NRC, DOE, Occupational Health and Safety Administration, the U.S. Geological Survey, etc,. could oversee this process. This approach would have the advantage that it would allow for direct, though necessarily limited representation from states and Indian tribes. Whether this is desirable in a program that would be focussed on research and development and whose mandate would exclude site selection (all possible geological formations would be carefully studied) is a matter for further debate.

Whatever the institutional vehicle chosen, certain principles will need to be observed, if the program is to be a successful one:

- the process, including the scientific research, must be public, and conducted to the highest norms of scientific integrity;
- clear management goals must be adopted, even for the research phase, so that the research actually produces results within a reasonable time frame (a few years to a couple of decades, depending on the problem);
- the long-term program must be clearly separated from the interests (both governmental and private) representing nuclear power plant manufacture, construction or operation or nuclear weapons production.

REFERENCES

1. Waste Isolation Systems Panel, A Study of the Isolation System for Geologic Disposal of Radioactive Wastes, National Academy Press, Washington, D.C., 1983; p. 229. (Hereafter cited as NAS, 1983.)

2. Robert E. Browning, NRC, letter to Ralph Stein, DOE, May 11, 1988; p. 3.

3. Panel for the Review of the Swedish KBS-3 Plan, Review of the Swedish KBS-3 Plan for Final Storage of Spent Nuclear Fuel, National Academy Press, Washington, D.C., March 1, 1984; p.2.

4. Ibid.; p. 3.

5. Ibid.; p 30.

6. Testimony of the National Association of Regulatory Utility Commissioners before the Subcommittee on Energy Research and Development, Committee on Energy and Natural Resources, U.S. Senate, September 12, 1985; p. 10.

7. Nuclear Waste Policy Act of 1982, Section 10101.12.

8. Nuclear Waste Policy Act of 1982, Section 10132(a) and 10141 (a) and (b).

9. NAS, 1983; p. 229.

10. NAS, 1983; p. 211.

11. Robert E. Browning, NRC, letter to Ralph Stein, DOE, May 11, 1988; p. 3.

12. Code of Federal Regulations, 40 CFR 191, Federal Register, May 8, 1984, June 21, 1983.

13. NAS, 1983; Section 8.5.

14. NAS, 1983; p. 225.

15. Code of Federal Regulations, 10 CFR 60, Federal Register, June 21, 1983; p. 28197.

16. Ibid.; p.28224.

17. Ibid.

18. Ibid.

19. NAS, 1983; Section 8.6.

20. NAS, 1983; p. 212.

21. Nuclear Waste Policy Act of 1982; Section 10132 (b).

22. NAS, 1983; p. 115.

23. A detailed discussion of the Hanford site and its problems is given in: Arjun Makhijani and Kathleen Tucker, Heat, High Water, and Rock Instability at Hanford: A preliminary Assessment of the Suitability of the Hanford, Washington Site for a High-Level Nuclear Waste Repository, Health and Energy Institute, Washington, D.C., February 1985.

24. "Review Comments by the U.S. Geological Survey on 'Site Characterization Report for the Basalt Waste Isolation Project,' DOE/Rl-82-3, forwarded to O.L. Olson of DOE by John B. Robertson of the U.S. Geological Survey, may 6, 1983.

25. Linda Lehman and Ellen J. Quinn, Comparison of Model Studies: The Hanford Reservation, internal NRC document # 8204200365-820330 PDR Waste, 1981.

26. Memorandum to Ellison S. Burton, Acting Director, Siting Division, Office of Geologic Repositories, October 10, 1984, page 3 entitled "Performance Assessment Problems -- BWIP [Basalt Waste Isolation Project]" by Basin manager S.V. Panno.

27. Ibid.

28. Ibid.

29. Ibid.

30. Office of Civilian Radioactive Waste management, Area Recommendation Report for the Crystalline Repository Project, Draft DOE/CH-15, Department of Energy, Washington, D.C., January 1986.

31. R.W. Davis, Review of Buried Crystalline Rocks of Eastern United States in Selected Hydrogeologic Environments Potentially Suitable for isolating High-Level Radioactive Waste, Water Resources 84-4091, U.S. Geological Survey, Louisville Kentucky, 1984.

32. NAS, 1983; p. 190.

33. P.A. Witherspoon et al., "Geologic Storage of Radioactive Waste: Field Studies in Sweden", Science, February 27, 1981; p. 894.

34. Office of Crystalline Repository Development, National Survey, OCRD-1 Department of Energy, Washington, D.C., 1983.

35. Luther J. Carter, "Nuclear Imperatives and the Public Trust: Dealing with Radioactive Waste", Issues in Science and Public Policy, Winter 1987; p.57. (Hereafter cited as Carter, 1987.)

36. Jerry S. Szymanski, Conceptual Considerations of the Death Valley Groundwater System with Special Emphasis on the Adequacy of this System to Accommodate the High-Level Nuclear Waste Repository, U.S. Department of Energy, Nevada Operations Office, Las Vegas, November 1987; pp. 5-5 and 5-6. (Hereafter cited as Szymanski, 1987.)

37. Szymanski, 1987; p. 5-6.

38. NAS, 1983; p. 185.

39. NAS, 1983; p. 186.

40. J.K. Bates, et al., Hydration Aging of Nuclear Wastes", Science, Vol. 218, October 1, 1982, pp. 51-53.

41. NAS, 1983; p. 188.

42. Szymanski, 1987; p. 5-1.

43. Szymanski, 1987; p. 5-5.

44. Robert E. Browning, NRC, letter to Ralph Stein, DOE, May 11, 1988; p. 1.

45. "NRC Staff Review of the Department of Energy's January 8, 1988 Consultation Draft Site Characterization Plan for the Yucca Mountain Site,", Final Point Papers, May 11, 1988; p. 2.

46. Robert R. Loux, Nevada Nuclear Waste Project Office, letter to C.E. Kay, DOE, September 6, 1988; p.3.

47. Memorandum from several Hydrologists and Hydrologic Technicians to Verne Schneider, Assistant Chief Hydrologist for Program Coordination and Technical Support,; Subject: "USGS role in Yucca Mountain Site Characterization Effort", August 17, 1988.

48. Ibid.

49. Ibid.

50. United Press International, "Bechtel Gets $1 billion pact for nuclear dump", Las Vegas Sun, December 11, 1988.

51. NAS, 1983; p. 265.

52. Carter, 1987; p. 66.

53. Kansas Geological Survey study, quoted in Carter, 1987; p. 70.

54. General Accounting Office, Nuclear Waste: Department of Energy's Transuranic Waste Disposal Plan Needs Revision, GOA/RCED-86-90, Washington, D.C., March 1986; p.3.

55. Bernd Franke and Arjun Makhijani, Avoidable Death: A review of the Selection and Characterization of a Radioactive Waste Repository in West Germany, Institute for Energy and Environmental Research, Takoma Park, November 1987.

56. Jim Kleinhan, letter to Congressman Ed Markey, August 28, 1985.

57. Arjun Makhijani, Comments on the Department of Energy's Draft Area Recommendation Report, National Committee for Radiation Victims, April 5, 1986; pp. 23-24.

58. Office of Civilian Radioactive Waste Management, Draft 1988 Mission Plan Amendment, U.S. Department of Energy, DOE/RW-187, Washington, D.C., June 1988; pp. 18-19.

59. Nevada Nuclear Waste Project Office, "Comments on U.S. Department of Energy Office of Civilian Radioactive Waste Management Draft 1988 Mission Plan Amendment (DOE/RW-1087, June 1988), Carson City Nevada, September 30, 1988; pp. 20-21.

60. Meyer Steinberg et al., "Apex Nuclear Fuel Cycle for Production of Light Water Reactor Fuel and Elimination of Radioactive Waste," Nuclear Technology, Vol. 58, September 1982, pp. 437-446.

61. Arjun Makhijani and Rick Tempchin, "Electric Utility Planning in Light of Global Climate Change Concerns," Institute for Energy and Environmental Research and Edison Electric Institute, draft paper, December 1988.

62. Gerhart Friedlander et al., Nuclear and Radiochemistry, third edition,Wiley, New York, 1981; pp. 157-158. (Hereafter cited as Friedlander, 1981.)

63. Friedlander, 1981; p. 157.

64. K.J. Schneider et al., High-Level Radioactive Waste Management Alternatives, 4 volumes, Battelle Pacific Northwest Labs, Richland, Washington, 1974; vol. 4, Section 9.

65. A very rough version of the energy argument against phototransmutation is as follows: Each fission of U-235 yields 200 MeV of energy. Light water reactor fuel contains about 3% U-235. After irradiation, it contains about 1% Pu-239, which we would like to transmute by photofission, by, say, 10 MeV photons. Since only 1% of the 10 MeV photons would reach Pu-

239, each photofission reaction in Pu-239 would require an input of 1,000 MeV of energy. Since there is only one-third as much plutonium-239 in spent fuel as there was U-235 in the first place, the energy required for photofission per fission of U-235 would be about 300 MeV -- which is 50% more than the energy generated from the U-235 fission. When conversion inefficiencies are taken into account, both in electricity generation, and gamma ray production, several times as much energy would be required to transmute a significant fraction of the plutonium-239 as was produced by the nuclear power plant.

66. Marvin Resnikoff, The Next Nuclear Gamble: Transportation and Storage of Nuclear Waste, Council on Economic Priorities, New York, 1984. (Hereafter cited as Resnikoff, 1984.)

67. Resnikoff, 1984; p. 17.

68. Resnikoff, 1984; p. 24.

69. Ibid.

70. General Accounting Office, Nuclear Health and Safety: DOE Needs to Take Further Actions to Ensure Safe Transportation of Radioactive Materials, GAO/RCED-88-195, Washington, D.C., September 1988; p. 19.

71. Office of Civilian Radioactive Waste Management, Initial Version Dry Cask Storage Study, DOE/RW-196, Department of Energy, Washington, D.C., August 1988.

72. Nuclear Energy Agency, Decommissioning of Nuclear Facilities: Feasibility, Needs and Costs, Report by an Expert Group, Organization for Economic Cooperation and Development, Paris; no date, but appears to have been published in 1984. We have assumed that the difference between the cost of dismantling after 100 years and the cost of immediate dismantling represents monitoring and security costs.

73. NUREG-0586, cited in Carter, 1987; p.23.

74. Robert Alvarez and Arjun Makhijani, "Hidden Legacy of the Arms Race: Radioactive Waste", Technology Review, Cambridge, Mass., August/September 1988.

75. Arjun Makhijani, Robert Alvarez, Brent Blackwelder, Deadly Crop in the Tank Farm: An Assessment of the Management of High-Level Nuclear Wastes in the Savannah River Plant Tank Farm, Based on Official Documents, Environmental Policy Institute, Washington, D.C., July 1986.

76. William Dietrich, Donna Orebic, Fay Fua, , "Survey of Spent Nuclear Fuel Storage", prepared by the Subcommittee on Nuclear Waste Disposal, for the Executive Committee of the National

Association of Regulatory Utility Commissioners, February 28, 1988.

77. Panel for the Review of the Swedish KBS-3 Plan, Review of the Swedish KBS-3 Plan for Final Storage of Spent Nuclear Fuel, National Academy Press, Washington, D.C., March 1, 1984; p.2.

78. Ibid.; p. 3.

79. Ibid.; p 30.