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Space Augmentation of Military High-Level Waste Disposal

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National Aeronautics and
Space Administration

Jet Propulsion Laboratory
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FOREWORD

This report - Space Augmentation of Military High Level Waste Disposal - summarizes the results of the second phase of a research project conducted by the Jet Propulsion Laboratory for the National Aeronautics and Space Administration (NASA). The first phase of this project resulted in publication of a report entitled "A Comparative Assessment of Terrestrial High Level Waste Disposal Options." The second phase of this research project focused on the technological, environmental and institutional limiting factors associated with space disposal of selected components of military high level waste. The remaining components of the waste are assumed to be disposed of on Earth.

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Dictionary of Abbreviations

AEC	Atomic Energy Commission
AU	Astronomical Units
CEQ	Council on Environmental Quality
DGEIS	Draft Generic Environmental Impact Statement
DOE	Department of Energy
EIS	Environmental Impact Statement
ERDA	Energy Research and Development Administration
EPA	Environmental Protection Agency
GEIS	Generic Environmental Impact Statement
HLW	High Level Waste
IRG	Interagency Review Group
LEO	Low Earth Orbit
MO	Mission Operations
MT	Metric Ton
NAS	National Academy of Sciences
NASA	National Aeronautics & Space Administration
NRC	Nuclear Regulatory Commission
NRDC	Natural Resources Defense Council.
OMB	Office of Management & Budget
ORNL	Oak Ridge National Laboratory
OSTP	Office of Science & Technology Policy
OTV	Orbit Transfer Vehicle
RCG	Radiation Concentration Guides
RSSF	Retrievable Surface Storage Facility
SIO	Scripps Institution of Oceanography

STS	Shuttle Transportation System
USGS	United States Geological Service

ABSTRACT

Space disposal of selected components of military high-level waste (HLW) appears to be possible by approximately the year 2,000. This disposal option offers the promise of eliminating the long-lived radionuclides in military HLW from the Earth.

Chapter I of this report examines the rationale for using space disposal for some HLW components. Chapter 2 examines the scope and nature of the present and projected military HLW disposal problem. A description of the 0.86 AU heliocentric nuclear waste disposal orbit option is presented, and some features of the safety requirements for this option are discussed. Chapter 3 presents a description of the interaction among EPA, DOE, NASA, NRC, the Congress and the President associated with the space disposal program.

In this study we have reached the following conclusions:

1. Since most high-level military waste is highly alkaline, and the radionuclides are extremely dilute, currently available chemical separation processes are inadequate for the space disposal option. Because of the payload capacity of the Space Shuttle, the concentration of actinides and/or major fission products from currently available processes for the chemical separation must be increased by one to two orders of magnitude in order to make space disposal a viable option for military waste.

2. A space mission which meets the dual requirements of long-term orbital stability (10^6 years), and a maximum of one Space Shuttle launch per week over a period of 20-40 years, is a heliocentric orbit about halfway between the orbits of Earth and Venus (0.86 AU). Examination of the mission scenario shows that some phases can be accomplished with existing technology or technology currently under development. Other phases would require the development of new systems. For example an Orbit Transfer Vehicle must be developed to take the payload from LEO to heliocentric orbit. Similarly, the development of a storable propellant stage is required in order to circularize the orbit of the payload around the sun.

3. Space disposal of high-level radioactive waste is characterized by long-term predictability and short-term uncertainties or "risks". An examination of the mission scenario shows that the risks associated with the following possible events must be reduced to acceptably low levels:

   (a) Catastrophic event at the launch pad.

   (b) Shuttle abort during either boost or LEO insertion phases.

(c) OTV failures during operations with nuclear waste package in LEO.

(d) OTV failure after leaving LEO.

(e) Storable propellant stage failure at perihelion.

4. Events 3(d) and 3(e) would leave the nuclear waste package in an unplanned and potentially unstable orbit. Since potential Earth reencounter and subsequent burn-up in the Earth's atmosphere is unacceptable, a deep-space rendezvous, docking and retrieval capability must be developed.

5. With a launch rate of one Shuttle per week, or one payload every two weeks, about a dozen simultaneous payloads need to be tracked in deep space.

6. Because of the complexity and the timing of major parallel activities in the space disposal option, extensive cooperation is required between DOE, NASA, EPA and NRC.

7. An examination of all major agency and technology interfaces shows that it may be feasible to begin operation of a space disposal system for selected components of military HLW by the year 2,000.

8. In order to enhance public acceptability of the space disposal option, NRC construction and operating licenses are recommended for major space disposal system components.

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CHAPTER I

INTRODUCTION

High-level nuclear waste is produced from both military application (such as nuclear weapons and nuclear submarines) and civilian nuclear power plants. The toxicity associated with this waste is extremely large and remains so for periods of time which are very long in terms of any time period associated with institutional controls. Based on the projected cumulative quantities of HLW in the U.S. by the year 2,000, Blomeke and Bond[1] calculate that 5.2×10^{16} m^3 of water would be required to dilute the HLW to the levels specified in Radiation Concentration Guides (RCG). According to USGS[2] "...this volume is almost double that of fresh water in global storage in lakes, rivers, ground water and glaciers. Even after a million years, the volume of water needed to dilute these wastes to the levels specified in the RCG is significant in terms of water stored in individual major lakes and aquifers." Hence, there is an urgent need to determine a method for disposing of HLW in a manner which is safe for a time period on the order of a million years. This unprecedented systems design and verification requirement imposes severe demands on the skills, abilities and imagination of the scientific and technical community. Nevertheless, many options for disposing of HLW have been suggested and partially studied.

1.1 HLW DISPOSAL OPTIONS

In the United States, the principal programmatic efforts have been directed at examining the option of disposal of HLW in bedded salt[3,4]. The U.S. has also engaged in a study program of HLW disposal in the sea-bed. Smaller study efforts have examined "ultimate disposal" techniques such as transmuting long-lived radionuclides into relatively short-lived radionuclides and disposal of the waste in space. The Swedish nuclear industry has examined the feasibility of HLW disposal in granite[5,6]. Options such as storing the waste on the polar caps appear to be ruled out due to uncertainties in climatology. Each of these terrestrial disposal options has significant scientific and regulatory uncertainties[7,8,9,10]. A combination of programmatic difficulties, scientific uncertainties and significant lack of public acceptance has caused previous U.S. plans for disposal of HLW to be modified. The Secretary of DOE was scheduled to submit a new nuclear waste management plan to President Carter on October 1, 1978. This plan was delayed until March 1979. This plan could have a significant impact on the public acceptability of nuclear waste disposal sites. According to the Wall Street Journal:[11]

> "So far, 11 states have barred a nuclear waste repository within their borders and 15 more are considering such bans...The future of nuclear power, which supplies 12% of the Nation's electricity may hinge on the waste issue. 'If the technicians and scientists don't come up with an answer soon, we ought to put a moratorium on new licensing,' threatens Sen. Gary Hart of Colorado, Chairman of the Senate Subcommittee on Nuclear Regulation. California and Maine already have banned new plant construction until an acceptable waste plan is developed--a policy that the President's Council of

> Environmental Quality advocates for the entire U. S. New York Gov. Hugh Carey recently said he will seek to bar future nuclear plants in his state because of the waste question...The resolution of the thorny nuclear waste issue will largely depend on the ability of politicians, elected for just a few years, to make judgments whose effects stretch thousands of years into the future. 'This is unlike other public-policy problems,' Rep. Udall sighs, 'The damn thing may be impossible.'"

Perhaps during this time of uncertainty and change it is appropriate to freshly examine the pros and cons, requirements, and timing associated with the space disposal option.

1.2 MILITARY HLW

This report constitutes a step in the direction of reexamining the space disposal option. It is aimed, however, at examining only the possibility of disposing of military HLW in space. This decision has been made because it does not appear currently feasible to use the next generation of space vehicles (the Shuttle) to dispose of spent fuel rods from commercial nuclear reactors since the Shuttle weight limitations would require an excessive number of flights. Furthermore, it is currently not possible to reduce this weight requirement by removing the uranium and the cladding from the commercial spent fuel because President Carter has indefinitely deferred reprocessing of commercial spent fuel. On the other hand, it should be noted that the military spent fuel has been previously reprocessed due to the requirement to extract the plutonium for nuclear weapons fabrication.

Extensive examinations of the status of the storage and disposal of military HLW have been performed[12,13,14,15,16]. A comparison of the military and the civilian HLW inventories by Krugmann and Von Hippel[17] indicates that the civilian inventory is comparable to the military inventory. The majority of the military HLW is stored in liquid storage tanks. The detailed form of the HLW in these tanks varies with location. For example the material in the Hanford tanks is in combinations of three different forms: salt cake, liquor and sludge. This military HLW is approximately 100 times more dilute than that projected for commercial HLW from nuclear power plants. In addition, the military liquid HLW that is presently stored in mild carbon steel tanks has had large quantities of sodium hydroxide added to neutralize the nitric acid in the waste. The waste was neutralized in order to prevent the nitric acid from dissolving the walls of the storage tanks. This addition of sodium hydroxide has increased the difficulty of performing subsequent chemical operations on the waste to selectively remove some of its components.

The liquid HLW at Savannah River is also neutralized and stored in steel tanks. The HLW at Idaho Falls has been calcined to the form of a dry powder in order to decrease its mobility in the soil in the event of a tank leak. Hence, the military HLW is presently stored in tanks in two forms: dry powder, and neutralized "liquid." Of course, the major question is not the form of the waste but what should be done to dispose of the waste.

An analysis of 27 options for disposing the HLW at Hanford indicates that the cheapest option is to leave the waste in the storage tanks and replace the tanks as necessary[12]. The National Academy of Sciences report indicates that this solution is unacceptable and that a non-institutional long-term solution for HLW disposal is required[15] (p. xiii). National governmental policy and regulations on this matter are not clear at present.

1.3 LICENSING UNCERTAINTIES

The NRC is required to license the disposal of all HLW[18]. The NRC regulations for licensing are predicated on the EPA's development of a numerical standard for HLW. This EPA standard was previously scheduled for 1977[3]. This schedule has not been met. Present indications are that the development of a standard for HLW disposal will be much more difficult than was previously expected. For example, many major objections and improvements were made to EPA's plan at an EPA sponsored waste management public forum held in Denver[19]. EPA presently estimates that it will complete its nuclear waste standard by 1985[20]. Clearly, the scientific uncertainties of terrestrial HLW disposal are much more difficult to resolve than was thought to be the case a few years ago. There may be fundamental limitations on the abilities of modern science and technology to ensure adequately safe terrestrial disposal of HLW.

It is even difficult for the technical community to settle on a set of criteria to determine the basic scientific data base that is required to scientifically determine the suitability of a site for HLW disposal. The USGS[7] (p. 9) has suggested a minimal set of requirements.

> "We need, as a minimum, the permeability and porosity of the media and the hydraulic head gradients all in three dimensions. In addition, we need to know the sorptive characteristics of the media along all paths, and we need to estimate the variable rates at which the solidified wastes will enter the transporting fluids. Needed, in particular, is information of the distribution and extent of major heterogeneities. The need for such data severely taxes both the available data base and the technology for generating it."

The ability of geologists to predict future geologic events has been questioned by the USGS, leading them to conclude that "Geology is basically a retrodictive rather than a predictive science." They further note that "...many processes probably can never modeled precisely" and that "...validating a waste management model for the timespans of concern will never be possible." Disposal of HLW in space may be a way to eliminate, or at least greatly reduce, these scientific and technological uncertainties. However, we must ensure that we don't trade one set of uncertainties for an equally dangerous alternate set.

1.4 SPACE DISPOSAL POSSIBILIES

The idea of disposing of nuclear wastes in space is not new. According to the "Lewis Report"[21] (p. 2) which was written in 1974:

"The Atomic Energy Commission (AEC) and the National Aeronautics and Space Administration, and others have suggested that radioactive nuclear wastes could be transported into space for disposal thereby eliminating the long-term storage of such wastes on Earch. This method potentially resolves the difficulties presented by controlled Earth storage of wastes that have decay half-lives measured in thousands of years." (Emphasis added)

A recent "Marshall Report"[22] (p. 1) concludes that space disposal is feasible although it notes a weight limitation for space disposal.

"The disposal of certain components of high-level nuclear waste in space appears to be feasible from a technical standpoint. Disposal of all high-level waste (Mix No. 1) in space is impractical because of the high launch rate required, and the resulting environmental impact, energy requirements, and economic factors. Thus, some form of waste separation will be required. A separation of just the unused uranium and cladding reduces the launch rate by a factor of 40." (Emphasis added).

A variety of potential destinations have been considered for space disposal of nuclear waste. These destination include:

- High Earth Orbit
- Earth-Moon Libration Points
- Moon Orbit
- Soft Landing on Moon
- Solar Orbit Between Orbits of Earch and Venus
- Solar Orbit Between Orbits of Earth and Mars
- Solar Impact
- Solar System Escape

The stability of orbits for these destinations has been examined. A SAI report[23] (p. 35) concluded that "Numerical techniques are presently inadequate for being able to integrate numerous orbits for 10^5 years in the Earth-Moon system in an economical fashion." Hence, the long-term stability of the High Earth Orbit, Earth-Moon Libration points, and the Moon Orbit is presently not sufficiently understood to use these destinations for HLW disposal. The possibility of soft land HLW on the Moon has been examined in the Marshall Report. This destination appears technically feasible and could result in long-term containment of the waste. According to this report:

"The only way that waste could return to Earth from the lunar surface would be as a result of meteoric impact, with some of the material achieving escape from the Moon and returning to Earth as a result of solar radiation pressure. The probability of the aforementioned happening is considered to be small; if it did happen, the amount of waste reaching the Earth would be very small."

SAI has shown that certain heliocentric orbits between Earth and Mars, and between Earth and Venus are stable for one million years.[1] The Marshall Report finds that "A good choice for a solar orbit would be a circular orbit inside the Earth's orbit at 0.86 AU from the Sun." (Ref. 23, p. 38). On the other hand, the Marshall report finds that "...a solar impact mission should be considered as impractical" due to the limitations of current chemical propulsion systems (emphasis added). The Marshall Report finds that solar system escape is possible with current chemical propulsion systems. However:

"The major disadvantage to the solar system escape mission is the 8,750 m/s ΔV required. This high energy requirement limits the OTV's payload to 687 kg per flight. Also, a failure during the OTV burn could leave the nuclear waste in a heliocentric orbit with a perihelion of 1 AU."

The payload for solar escape (687 kg) is smaller than the payload for the 0.86 AU heliocentric orbit (4,450 kg).

Thus, the technical possibility exists for at least three destinations for high-level nuclear waste disposal. These are:

- Solar Orbit between Earth and Venus
- Solar Orbit between Earth and Mars
- Soft Landing on the Moon

NASA's current HLW disposal program is emphasizing the 0.86 AU heliocentric orbit. The remainder of this report will concentrate on this disposal destination.

1.5 UNIQUENESS OF SPACE DISPOSAL

The laws governing the movement of heavenly bodies within the solar system are well established and validated. Furthermore, these laws have a certain degree of simplicity and elegance. It is possible to predict the motions of heavenly bodies for millions of years with an high degree of confidence in the accuracy of the calculations. To date the calculations that have been performed indicate that if a HLW disposal package is correctly put into a 0.86 AU heliocentric orbit, it will remain in that stable orbit for at least one million years. Hence, space disposal appears to be characterized by long-term predictability.

This clearly contrasts with the various terrestrial disposal options which are hampered by features such as geology not being a predictive science, the absence of an adequate scientific data base for the evaluation of waste disposal sites, the influence of climatic changes, changes in groundwater distribution, earthquakes, etc. However, the terrestrial disposal options are presently characterized by short-term predictability. It appears that the technology is well in hand for digging tunnels, shafts, etc. associated with, for example, bedded salt disposal systems. Similarly, it is possible to immobilize HLW in a glass, package it, and place the container safely in a disposal site. If the disposal site is discovered to have some serious problem after a set of HLW canisters has been emplaced, they can be retrieved, if retrievability is designed into the system.

In order for the space disposal option to receive a high degree of public acceptability, the Government must be able to establish, beyond any reasonable doubt, that the space disposal system is safe in both the short-term and the long-term. It would be highly undesirable to trade the waste disposal risks spread over perhaps a million years for comparable risks that would occur in a single day! To ensure safety, extensive analysis and proof testing must be performed on all components of the space disposal system for all phases of the mission including the following phases:

- Transportation to launch site
- Handling at launch
- Launch
- Ascent to low Earth orbit
- Operations in low Earth orbit
- Trajectory to 0.86 AU
- Insertion into orbit at 0.86 AU

Example requirements for these mission phases will be examined later in this report. Since space disposal of HLW appears technically possible, it is appropriate to examine the potential HLW payload to space in more detail.

1.6 PAYLOAD TO SPACE

According to the Marshall Report[22] (p. 15) spent fuel rods are considered as "unsuitable for space disposal because it is simply too massive for transport (i.e., high flight numbers). Further, it has an unfavorable energy penalty and poor economics." Hence, a payload more suitable to the space option is required. If the space disposal option is viewed as an augmentation of the terrestrial disposal of HLW then certain components of the HLW could be disposed of in space whereas other components could be disposed of on Earth. Perhaps radionuclides which have half-lives greater than the order of one-hundred years, and which constitute a significant toxic hazard would be candidates for space disposal. The other radionuclides in the HLW would be suitably disposed of on Earth. The quantitative distribution of HLW mass as a function of radionuclide characteristics is examined later in this report. Designing a terrestrial HLW disposal system to isolate the

radionuclides from the biosphere for 1,000 years should certainly be much less difficult than designing a million year repository.

If a space augmentation scheme for HLW disposal were to be pursued, chemical processes and technologies would have to be developed to separate the long-lived, toxic radionuclides from the various forms of military HLW. R&D budgets would have to be adjusted in accordance with the relative priority of this waste disposal option. As part of this contemplated effort, economic studies would be required in order to assess the influence of this option on the overall military HLW waste management cost. Environmental studies of this option would be needed, since the processing of the waste would create "side streams" which could have significant environmental impacts. In addition, an overall plan involving governmental agencies such as NASA, DOE, EPA, USGS, etc. would be required. Some aspects of such a plan are examined later in this report.

CHAPTER 1

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CHAPTER II

MILITARY HLW AND SPACE DISPOSAL

2.1 MILITARY WASTE - EXISTING AND PROJECTED

Very impressive characteristics of the stored military waste are its enormous physical volume and the extreme dilution of the radionuclides. At Hanford the in-tank waste consists of the following components:

- 11 million gallons of bulk sludge consisting mainly of insoluble metal oxides and hydroxides, with a specific gravity of 3.0
- 25 million gallons of salt cake (mostly sodium nitrate) deposited over the sludge, with a specific gravity of 1.75
- 11 million gallons of caustic liquid, with a specific gravity of 1.5
- 3 million gallons of liquid waste awaiting concentration

Tables 1 and 2 (Reference 1) list the radioactivity inventory of the in-tank Hanford waste, and Table 3 (Reference 2) shows the mass distribution of the radionuclides. About 0.4 MT of plutonium and 0.014 MT of americium-241 remain in the waste, mostly in the sludge, out of a total sludge mass of about 90,000 MT. The in-tank strontium 90 and cesium 137, which are the dominant radionuclides for the first 500 years (Figure 1), each amount to about 0.3 MT, out of a total of 350,000 MT of sludge, salt cake, and residual liquid combined.

It should be noted that about 0.45 MT of ^{90}Sr and 1.4 MT of ^{137}Cs have already been separated from the in-tank wastes described above. These are either encapsulated in double-walled metal cylinders immersed in a storage pool, or are awaiting encapsulation. Each cylinder contains up to 150,000 curies (average 100,000 curies, or about 0.7 kg) of strontium fluoride, or 80,000 curies (average 65,000 curies or about 1 kg) of cesium chloride. Furthermore, each capsule contains an additional 100 cubic feet (about 5 MT) of other HLW constituents which were not chemically separated from the cesium and the strontium.

The waste volumes and radioactive inventory at Hanford just described have resulted from reactor operations during the period 1944-1971. Since 1972, spent fuel discharged from the single reactor still in operation has been accumulating in fuel storage basins. An estimate of the impact of future wastes generated at Hanford depends critically on the decision whether or not to resume reprocessing in the Purex Plant. If reprocessing of spent fuel is resumed in 1978, in-tank waste volumes will be increased by approximately 5 percent by 1990. If ^{90}Sr and ^{137}Cs are recovered directly from the acid wastes the number of capsules containing strontium and cesium will be increased by about 40 percent by 1990 (Reference 1).

The high-level waste inventory at Savannah River differs in detail from the Hanford inventory, but has the same basic characteristics (Reference 3). If waste removal from the storage tanks is initiated in 1985, the 31 tanks in service will contain 13.3 million gallons of damp, crystallized salt, 3.4

million gallons of sludge, and 5.6 million gallons of liquid waste. At Savannah River the strontium and cesium have not been removed from the waste and encapsulated (Reference 3, p. III-7). The HLW at Idaho Falls has been calcined to the form of a dry powder in order to decrease its mobility in the soil in the event of a tank leak.

TABLE 1. (Reference 1)

Inventory of Major Fission Products in
Hanford High-Level Waste Decayed to 1990
(From Reactor Production — 1944 - 1971)
(Curies)

Radionuclide[a]	Salt Cake[b]	Sludge[b]	Residual Liquor[b]	Capsules	Total
^{3}H	*	*	1.1×10^{4}	—	1.1×10^{4}
^{14}C	*	*	*		$<1.6 \times 10^{4}$
^{79}Se	*	8.2×10^{2}	*	—	8.2×10^{2}
^{90}Sr	2.0×10^{6}	4.5×10^{7}	6.0×10^{5}	5.8×10^{7}	1.1×10^{8}
^{93}Zr	*	6.9×10^{3}	*	—	6.9×10^{3}
^{99}Tc	*	*	3.1×10^{4}	—	3.1×10^{4}
^{106}Ru	*	3.7×10^{1}	3.7×10^{1}	—	7.4×10^{1}
^{107}Pd	*	5.7×10^{1}	*	—	5.7×10^{1}
^{113m}Cd	*	5.0×10^{3}	*	—	5.0×10^{3}
^{121m}Sn	*	1.1×10^{2}	*	—	1.1×10^{2}
^{126}Sn	*	6.8×10^{1}	*	—	6.8×10^{1}
^{125}Sb	*	2.0×10^{4}	*	—	2.0×10^{4}
^{129}I	*	*	4.7×10^{1}	—	4.7×10^{1}
^{134}Cs	1.2×10^{2}	1.2×10^{2}	4.3×10^{2}	2.5×10^{3}	3.2×10^{3}
^{135}Cs	4.4×10^{1}	4.4×10^{1}	1.6×10^{2}	9.0×10^{2}	1.1×10^{3}
^{137}Cs	5.0×10^{6}	5.0×10^{6}	1.8×10^{7}	1.0×10^{8}	1.3×10^{8}
^{144}Ce	*	9.9×10^{0}	*	—	9.9×10^{0}
^{147}Pm	*	1.0×10^{6}	*	—	1.0×10^{6}
^{151}Sm	*	1.4×10^{6}	*	—	1.4×10^{6}
^{152}Eu	*	1.5×10^{3}	*	—	1.5×10^{3}
^{154}Eu	*	7.3×10^{4}	*	—	7.3×10^{4}
^{155}Eu	*	7.4×10^{4}	*	—	7.4×10^{4}

a. Daughter nuclides in decay chains are not listed. Curie values are for parent nuclide only.

b. Radionuclides present in trace quantities are indicated by an asterisk.

TABLE 2. (Reference 1)

Inventory of Major Actinides in
Hanford High-Level Waste Decayed to 1990
(From Reactor Production — 1944 - 1971)
(Curies)

Radionuclide[a]	Sludge
^{233}U	4.0×10^{2}
^{235}U	1.3×10^{1}
^{238}U	3.0×10^{2}
^{237}Np	1.0×10^{2}
^{238}Pu	4.0×10^{2}
^{239}Pu	2.1×10^{4}
^{240}Pu	5.2×10^{3}
^{241}Pu	6.0×10^{4}
^{241}Am	5.0×10^{4}

a. Salt Cake and Residual Liquor contain trace quantities of these isotopes.

TABLE 3. (Reference 2)

Hanford Tank Wastes: Inventory of Important Radionuclides ($T_{1/2} \geqq 0.5$ year) as of Mid-1977 (Average Post-Fission Time is 20 Years). Estimates are Based on Production Records[a] or are Calculated from ^{235}U Fission Yield[b]

	Fission Products[b]			Actinides[a]	
	(curies)	(grams)		(curies)	(grams)
Se-79	8.6×10^2	1.2×10^4	U-233	4×10^2	4×10^4
Sr-90[a]	4.7×10^7	3.3×10^5	U-235	1.3×10^1	6×10^6
Zr-93	4.3×10^3	1.7×10^6	U-238	3.0×10^2	9×10^8
Tc-99[a]	3.1×10^4	1.8×10^5	Np-237	1.1×10^2	1.5×10^5
Ru-106	5.3×10^2	1.6×10^{-1}	Pu-238	4.5×10^2	2.6×10^1
Cd-113m	1.8×10^2	7.7×10^{-1}	Pu-239	2.1×10^4	3.4×10^5
Sn-126	7×10^2	2.4×10^4	Pu-240	5.2×10^3	2.3×10^4
Sb-125	6.5×10^4	6.2×10^1	Pu-241	6.3×10^4	5.5×10^2
I-129[a]	7.3×10^1	4.4×10^5	Pu-242	2×10^0	5.2×10^2
Cs-134	3.1×10^4	2.3×10^1	Am-241	4.5×10^4	1.4×10^4
Cs-135	4.8×10^2	6.2×10^5	Am-242m	<5	$<5 \times 10^{-1}$
Cs-137[a]	2.8×10^7	3.1×10^5	Am-243	<1	<5
Ce-144	4.2×10^1	1.3×10^{-1}	Cm-244	<5	$<10^{-1}$
Pm-147	3.3×10^6	3.6×10^3			
Sm-151	4.6×10^6	1.6×10^5			
Eu-152	3.9×10^3	2×10^2			
Eu-154	3.5×10^5	2.5×10^2			
Eu-155	4.1×10^3	3.2×10^0			

[a] Inventories of actinides and four fission products (^{90}Sr, ^{99}Tc, ^{129}I, ^{137}Cs) were estimated by O. F. Hill, Atlantic Richfield Hanford Co., personal communication, 1977, from: (a) total reactor and separation operations; (b) recoveries of separated ^{90}Sr, ^{137}Cs, and ^{237}Np from wastes; and (c) some analyses of tank contents after separation of ^{90}Sr, ^{137}Cs, and ^{237}Np.

Although the half life of ^3H is 12.3 years, it has been excluded, because at all stages of separations operations and volume reduction (evaporation) ^3H follows the water or water vapor phase. As of this date, most of the ^3H originally produced has been lost to ground or airborne effluents. The small amount remaining in the tanks will be volatilized, if the wastes are solidified by a heating process.

It has been assumed that all of the ^{129}I produced is present in the tanks. That is an overestimate, because some ^{129}I was volatilized and dissipated with airborne effluents during the original Pu separations.

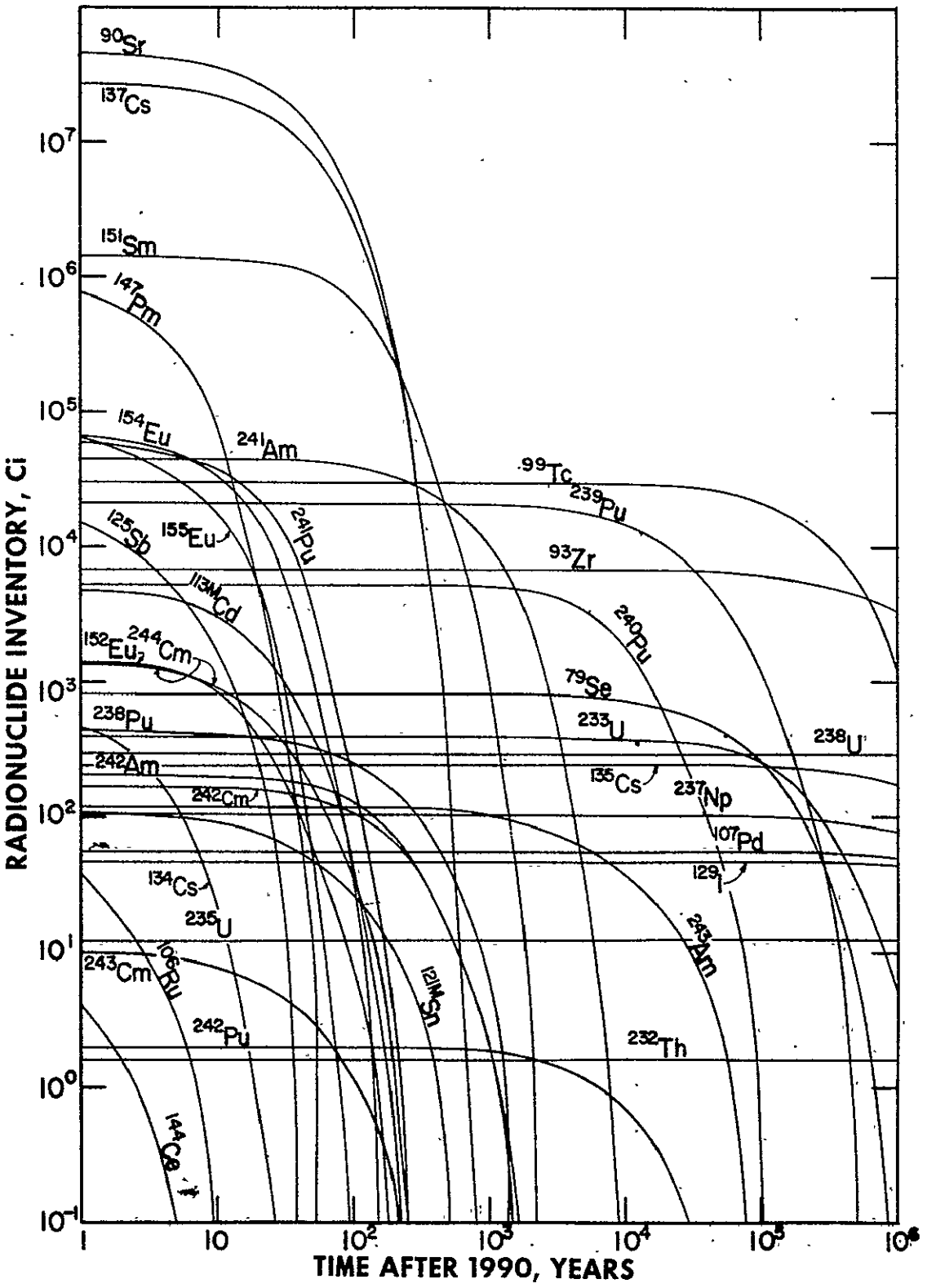
The ^{90}Sr and ^{137}Cs remaining in the tanks are about 37 and 20 percent, respectively, of the total inventory. The balance of those nuclides has been separated and is temporarily stored in separate tanks or has been solidified and encapsulated and is stored in a water basin in B plant.

About 90 percent of the ^{237}Np produced has been separated and shipped offsite as starting material for ^{238}Pu production.

[b] Calculated by P. W. Durbin from ^{235}U fission yield given in ERDA-1538:Table III-D-2, and the quantity of ^{99}Tc given by O. F. Hill, corrected for 20-year decay. For example, Table III-D-2 shows at 20 years 193 curies of ^{93}Zr and 1,400 curies of ^{99}Tc; Hill's table shows 31,000 curies of ^{99}Tc. Total $^{93}Zr = 1.93 \times 10^2 \times 3.1 \times 10^4 / 1.4 \times 10^3 = 4{,}300$ curies.

FIGURE 1. (Reference 1)

Radionuclide Content of In-Tank Waste



2.2 PROCESSING OF MILITARY WASTE FOR DISPOSAL

Three approaches to the problem of the terminal disposal of high-level military wastes in space are identified in Figure 2. Based on using currently available technology, each of these approaches presents formidable problems for the space option.

1. The first approach is based on a process discussed in the Hanford Defense Waste Document which removes the Pu, ^{241}Am and ^{99}Tc, which are long-lived actinides and fission products. If these radionuclides are disposed of in space, this approach reduces the rest of the high-level waste to a 500-700 year problem. However, it should be noted that if this chemical separation process is used the actinides and long-lived fission products are mixed with about 7,000 MT of alkaline waste. If the assumption is made that 4.4 MT of waste can be put in a 0.86 AU solar orbit for each pair of shuttle launches (Reference 4, pg. 38), then approximately 3,200 shuttle launches would be required to eliminate the Pu, Am and Tc from the Hanford HLW. Hence, the alkali waste associated with process #1 must be reduced by about two orders of magnitude in order to reduce the number of shuttle launches to more feasible limits.

2. The second approach not only removes the Pu, Am and Tc but also removes 99.99% of ^{137}Cs and ^{90}Sr, for subsequent disposal in space. On a laboratory scale the removal of strontium and actinides by carrier precipitation with inert strontium phosphate has been demonstrated, according to the Hanford Defense Waste Document (Reference 1, p. 5-17):

> "Recent laboratory studies have shown that the removal of strontium and actinides from salt solutions by sodium titanate, an inorganic ion exchanger, is a very effective method which can be used along or in conjunction with carrier precipitation.
>
> Some residual liquors and salt cake solutions contain organic complexants that interfere with the removal of strontium-90 (^{90}Sr) and actinides. Laboratory studies have shown that ozonation of the solutions will oxidize the complexants to carbon dioxide and/or organic material that do not inhibit removal of ^{90}Sr by precipitation or sorption techniques. Some precipitation of strontium also occurs during ozonation.
>
> The technology for removal of cesium and technetium from salt solutions by ion exchange with cation and anion resins, respectively, has been demonstrated."

Figure 3 illustrates the various steps in process #2.

A considerable research and development effort is required to scale-up these laboratory studies to the pilot plant level. But the main difficulty with this procedure for the space option is that about 5 percent of the inert components are carried along with the fission products and actinides. Thus, for the Hanford waste the output of the radionuclide removal process is approximately 2.4 million gallons of powdered high-level waste, or about 20,000 MT. Taking into account the payload capacity of the Space Shuttle, the

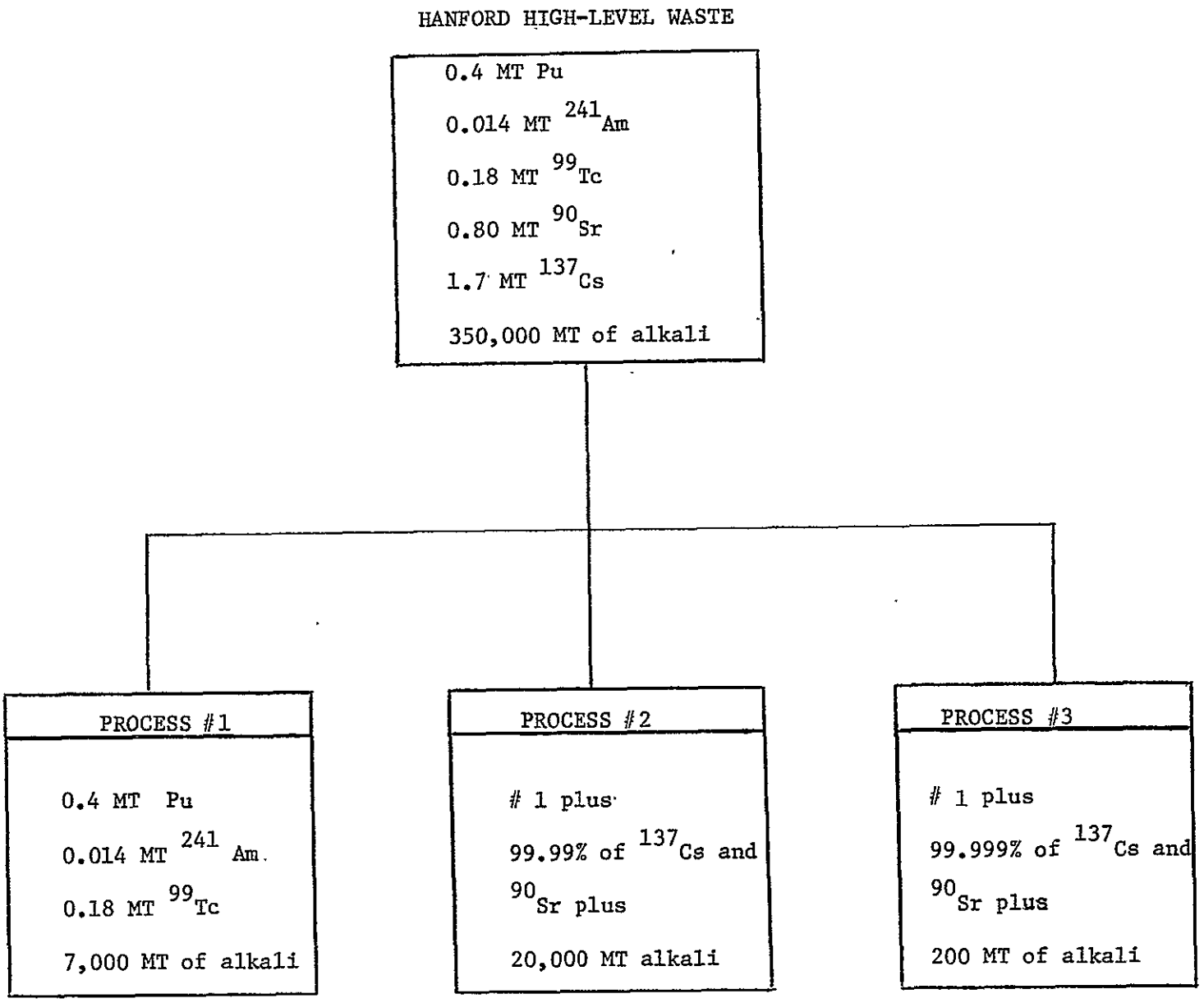


FIGURE 2

The output of three processes for removing selective components of the Hanford HLW. The first two processes are based on current literature. The third process is hypothetical.

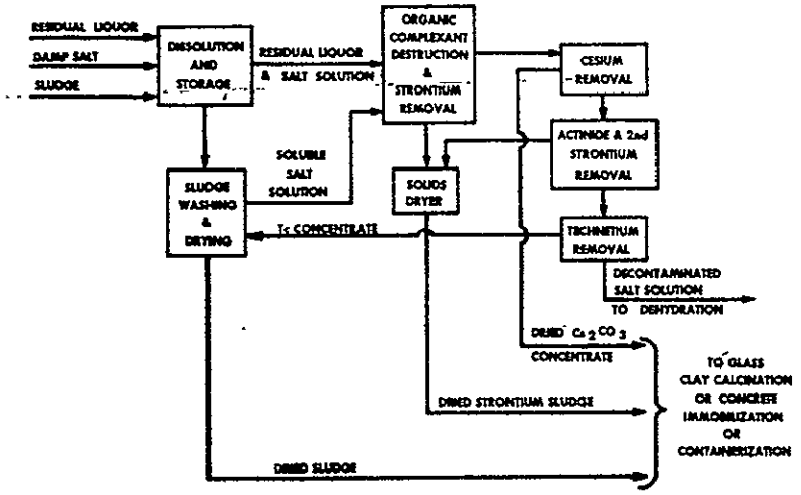


FIGURE 3.

Process #2 for removing Pu, Am, Tc and ^{137}Cs & ^{90}Sr for subsequent disposal in space.

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concentration of actinides and major fission products in the high-level waste must be increased by about two orders of magnitude in order to make space disposal a potentially viable option for military waste.

3. The third approach is based on the removal of 99.999% of ^{137}Cs and ^{90}Sr in addition to the Pu, Am and Tc removed in process #1. This method does not now exist. From Figure 1 it can be shown that this approach would reduce the radioactivity content of the remaining waste to about 3000 Ci and would enable it to be handled as low-level waste (10^{-9} Ci/gm). However, as a part of this idealized process, some method would have to be developed to reduce the waste accompanying these fission products by two orders of magnitude to about 200 MT of alkali. If this were done, about 90 shuttle launches would be required to dispose of the Hanford HLW.

2.3 DESCRIPTION AND REQUIREMENTS OF SPACE OPTION

Over the past years NASA studies have examined a number of possible space destinations for military HLW disposal (see Section 1). Emphasis is currently being given to emplacing the HLW in a heliocentric orbit. The primary criteria for selection of a baseline space orbit are: (1) stability of the orbit for at least one million years in order to allow for decay of the actinides and their daughter products to harmless levels; (2) low energy requirements to inject the waste package into this orbit. Another way of stating the second criterion is that the payload capability of the propulsion system should be large enough so that not more than one Space Shuttle launch per week is required over a period of 20-40 years in order to dispose of the military HLW in space. The space mission that best meets these requirements is an orbit around the Sun about halfway between Earth and Venus (0.86 AU). This mission has been selected by NASA for more intensive study. The payload for this orbit including waste and canister is about 5 MT (Reference 4, pg. 97).

A brief step-by-step examination of the mission scenario is helpful in identifying those elements for which technology already exists, and those elements for which new technology or engineering development is required. This mission involved the launch of two Space Shuttles per waste payload: one Shuttle carries the waste package and a small solid propellant second stage that places the payload into its orbit around the Sun. The second Shuttle carries an orbital transfer vehicle (OTV). The sequence of events is as follows:

(1) Launch of Shuttle No. 1 carrying the fueled OTV without a HLW payload into low Earth orbit (LEO).

(2) Development of OTV in low Earth orbit (LEO) and complete checkout of OTV propulsion and attitude control systems by Shuttle No. 1 astronauts.

(3) Launch of Shuttle No. 2 carrying the nuclear waste package to near-rendezvous with the OTV now separated from Shuttle No. 1.

(4) Removal of waste package from Shuttle No. 2 by using remote manipulator arms. Final checkout of stabilization of package.

(5) Withdrawal of Shuttle No. 2 to a covenient distance and docking of OTV with waste package.

(6) Removal of protective "cocoon" from waste package as the OTV backs away carrying the waste package. The "cocoon" includes the reentry thermal protection system, mechanical containment, and gamma ray shield.

(7) Burn of OTV engine (ΔV = 3260 m/sec) to place the waste package and its storable propellant stage on an elliptical transfer path from LEO to a perihelion of 0.86 AU six month later. Separation of OTV from waste package after burn, and return of OTV to LEO.

(8) Upon arrival of waste package at perihelion of 0.86 AU the orbital insertion stage engine is ignited (ΔV = 1190 m/sec) to circularize orbit of waste package around the sun.

(9) Retrieval of OTV by Shuttle No. 1 and retrieval of cocoon by Shuttle No. 2. Return of Shuttles to Earth.

Some phases of this mission scenario can be accomplished with existing technology or technology under development. Other phases would require new development, e.g., develop a suitable OTV. But, as pointed out in Section 1, the "risk" in both the short-term and long-term must be reduced to acceptably low levels. Four classes of possible accidents require the extension of existing systems or the development of new systems. Each of these situations is discussed briefly below: (See also Reference 4).

(a) Catastrophic event at the launch pad.

A remotely controlled, manually activated means of ejecting the payload is required to take care of the low, but non-zero probability of a catastrophic event at the launch pad (Reference 4, pg. 87). A back-up automatic ejection of the payload is also required in case the manual system should become inoperative. During this event the payload must remain intact.

(b) Waste package Shuttle abort during either boost or LEO insertion phases.

In the event of an abort in flight, NASA risk analyses consider dumping of excess Shuttle propellant prior to landing in order to minimize explosive potential since the waste package is still aboard the Shuttle. In the event of less serious failures, such as not acquiring proper LEO orbit, a back-up Shuttle could be provided to repair the failed Shuttle (No. 2), or to transfer or retrieve the payload in orbit. Ejection of the payload is also possible.

(c) OTV failures during operations with nuclear waste package in LEO.

A means of ejecting the payload from the OTV must be provided. The payload itself is designed with a reentry heat shield and mechanical containment system, including aerodynamic braking and parachutes, in order to keep the nuclear waste package intact during water or land impact. The payload must be designed so that it will either float in sea water, or release a "trailing wire" to communicate its position if it should sink. Search and recovery aids such as transponders, sonar, and dye markers must also be included in the "cocoon." If the payload ejection system fails, a recovery plan must be available to retrieve the waste package.

(d) After leaving LEO: OTV abort or storable propellant stage abort.

Once the "cocoon" is removed, certain failures of the OTV during the long burn, or failures in the small solid propellant stage at perihelion would leave the nuclear waste package in an unplanned and unstable orbit without its protective system. Since potential Earth reencounter and subsequent burn up in the earth's atmosphere is unacceptable, a method of dealing with this potential problem is required. This possibility requires the development of a deep-space rendezvous, docking and retrieval capability that does not now exist. The nuclear waste package must be equipped with a transponder so that it can be located in deep space.

In this connection it seems clear that the nuclear waste package should be periodically tracked along its 6-month elliptical transfer path from LEO to perisol, and probably for some period of time after circularization of its orbit around the Sun. With a launch rate of one Shuttle per week, or one payload every two weeks, about a dozen simultaneous payloads need to be tracked in deep space.

CHAPTER 2

REFERENCES

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2-3. "Alternatives for Long-Term Management of Refined High-Level Radioactive Waste: Savannah River Plant, Aiken South Carolina," ERDA 77-42/1, May, 1977.

2-4. Burns, R. E., W. E. Causey, W. E. Galloway and R. W. Nelson, "Nuclear Waste Disposal in Space," NASA Technical Paper, Marshall Space Flight Center, December, 1977.

CHAPTER III

INTERAGENCY AND REGULATORY INTERACTIONS

The development of a viable program for space augmentation of military HLW disposal will require extensive interaction between the governmental agencies involved, the Congress, the President, the involved states, and the American public, since the issues involved in radioactive waste management are diverse and significant. These issues have recently been examined by the NRC (References 1 and 2). An analysis of the history of U.S. waste management has been critical of the way waste management policy has been conceptualized, especially because of uncritical faith in the technological fix. "Past AEC practices of virtually ignoring critical outsiders need to be reconsidered." (Reference 1, pg. 15). However, "No system has, in fact, been implemented for disposing of high-level wastes." (Reference 1, pg. 53). "There appears to be extraordinary uncertainty regarding the consequences of error in the management of wastes." (Reference 1, pg. 54 with emphasis added.) A properly conceptualized and carried out space disposal program could considerably reduce these uncertainties. However, first the agencies must develop plans and alternatives for the technology and regulations governing HLW disposal. The Congress and the President must approve and fund these plans, and the general public must consider the plans to be acceptable. This chapter focuses on the part of this process dealing with the interaction among federal governmental agencies.

3.1 PRINCIPAL AGENCIES

The military HLW results principally from reprocessing irradiated uranium as part of the nuclear weapons program and also from the nuclear submarine program. Since these are ongoing programs any major decisions involving military HLW will involve the Department of Defense (DOD). This is particularly the case if the cost of a particular waste disposal option comes out of the DOD budget. The Department of Energy (DOE) is responsible for development of the technology for HLW disposal, and presumably the disposal of the waste. The Environmental Protection Agency (EPA) is responsible for promulgating a set of numerical standards for the disposal of HLW. The Nuclear Regulatory Commission (NRC) is responsible for writing regulatory criteria to ensure that the EPA standards are met. Based on these criteria, DOE's HLW disposal plans and systems will be examined by NRC to determine whether or not to issue a license.

In the case of the space disposal option, the National Aeronautics and Space Administration (NASA) would play a vital role. A proposed division of responsibilities between DOE and NASA is shown in Figure 4. NASA would be responsible for safety system development at the launch site and in space. NASA would also be responsible for launch site development and modifications. DOE would be responsible for developing storage sites, a ground transportation system and a waste factionation system. NASA and DOE would jointly consider such items as operations, safety, cost, waste container, abort and environmental impacts.

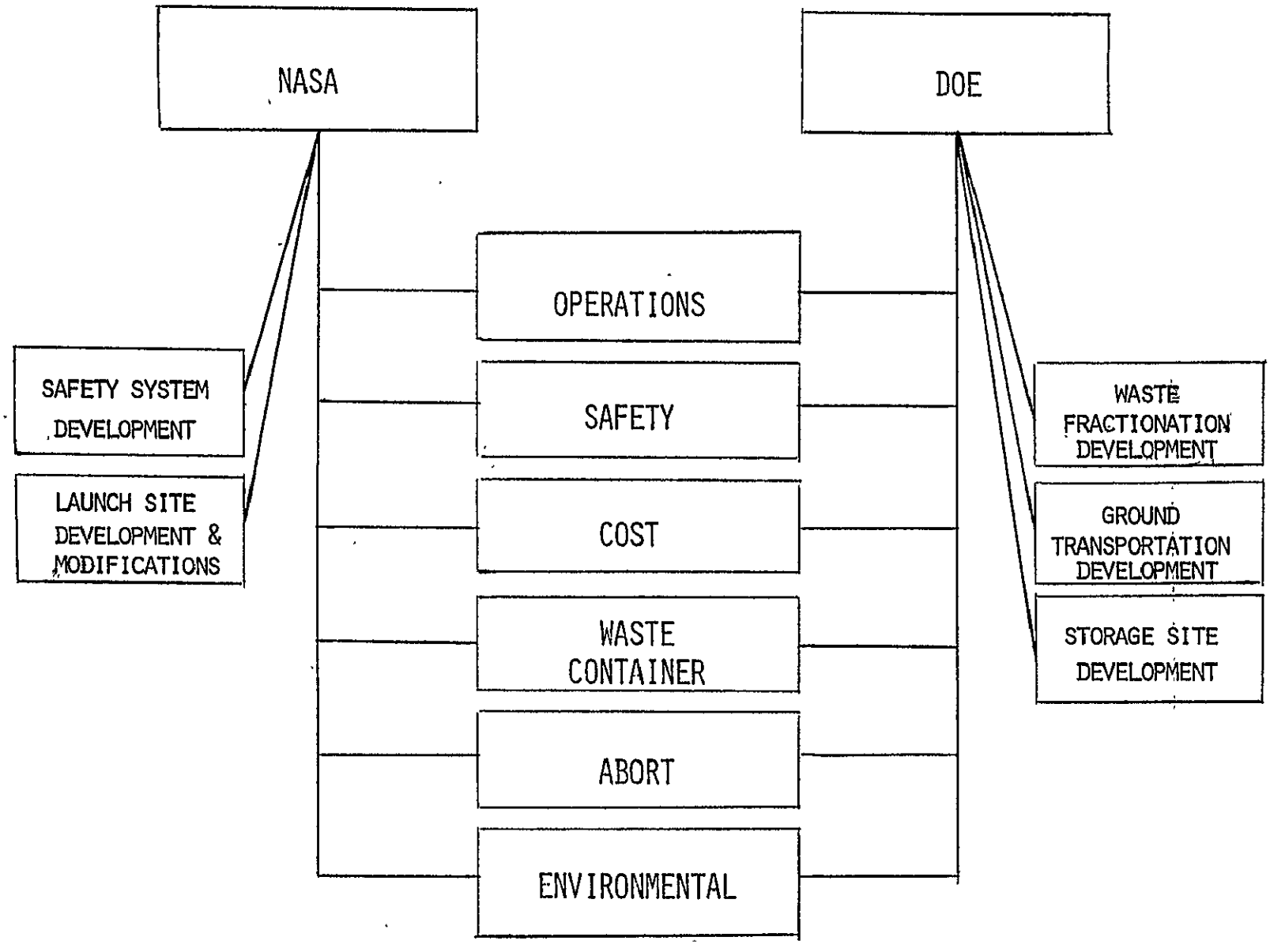


Fig. 4

Schematic of NASA and DOE Interfaces for Space Disposal

The above provides a broad outline of responsibilities for the principal agencies involved in a HLW space disposal program. Other agencies sugh as the U.S. Geological Survey (USGS), the President's Office of Science and Technology Policy (OSTP), and the Council on Environmental Quality would probably also take an active role in the development and evaluation of the space disposal option. The goals, responsibilities, budgets, manpower required, timing and the principal interactions of these agencies within the space disposal program would have to be formulated in detail. The next section provides our interpretation of some of the interactions along with comments on potential timing for the space disposal option.

3.2 HISTORICAL PERSPECTIVE

Before examining the interactions and timing required for the space disposal option, it is useful to review the history of previous programs for geological disposal of HLW. It is apparently difficult to accurately forecast schedules for the development of HLW disposal systems. In 1957 the National Academy of Sciences' Committee on Waste Management reported "The most promising method of disposal of high-level waste at the present time seems to be in salt deposits." (Reference 3) According to the NAS analysis, four years later, the same advisory committee reported "Experience both in the field and in the laboratory on the disposal of wastes in salt have been very productive and well conceived; plans for the future are very promising." (Reference 2, pg. 4) In June of 1970, a decision was made to locate a HLW disposal site at Lyons, Kansas. By February of 1972 the Lyons project was officially dead (Reference 2, pg. 4). The concept of the Retrievable Surface Storage Facility (RSSF) was announced in May 1972. In April of 1974 the Administrator of ERDA, R. Seamans, withdrew his request for funds to build a RSSF (Reference 2, pg. 8). In March of 1976 an Ad Hoc Interagency Task Force on Commercial Nuclear Waste Management was formed to ensure internal compatibility of the Federal Government's HLW activities. The task force was chaired by OMB, and included representatives from CEQ, EPA, ERDA, NRC and USGS. This group forecasted operation of a repository for commercial HLW by 1985 (Reference 4, pg. 17). The 1985 target date is no longer feasible (Reference 5). A new plan is being developed by the Interagency Review Group on Nuclear Waste Management, which is headed by DOE Secretary Schlesinger. The report from this group was previously due to be delivered to President Carter by October, 1978. The report was finalized in March , 1979. Preliminary indications are that a commercial repository can not be made operational before 1989. Hence, the "schedule" appears to have slipped four years in the last two years. The 1989 schedule assumes that NRC issues a license for the HLW repository before EPA completes its promulgation of numerical standards for HLW. The public acceptability of this shortcut needs to be determined. If this approach is not considered acceptable, NRC may have to wait until EPA's standard is issued before finalizing its regulatory criteria. If EPA's standard were completed in 1985, as is currently estimated, then the 1989 date could not be met. Scheduling of a HLW disposal plan may continue to be very difficult until the public's concern of the uncertainties involved is substantially diminished. Perhaps a careful development of the space disposal option would decrease public concern about HLW disposal.

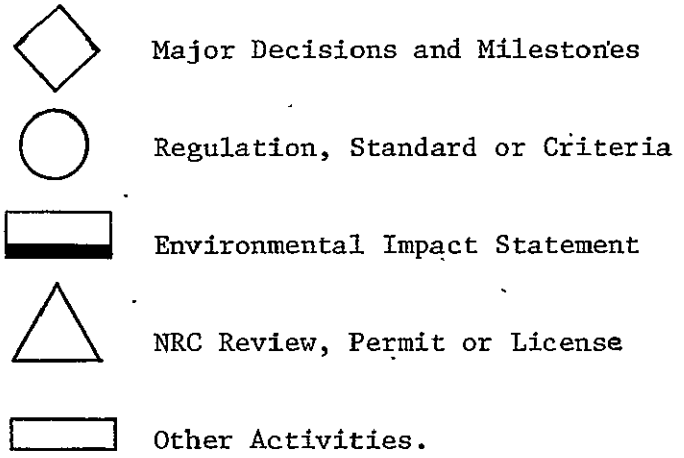
3.3 SPACE DISPOSAL INTERACTIONS AND TIMING

Development of a complete system for space disposal of selected components of military HLW requires the performance of many interrelated activities on the parts of NRC, EPA, NASA and DOE. For the purpose of discussion, we have arranged these activities in the following five principal categories:

- Major Decisions and Milestones
- Waste Retrieval System
- Waste Chemical Extraction and Solidification System
- Space Disposal System, and
- Space Specific Standards, Criteria and Regulations.

The relationships among these categories is depicted in Figure 5. The categories are indicated by dashed lines in Figure 5. The dashed lines enclose the activities which occur within each of these principal categories. Solid lines are used between two or more activities to indicate that the initiation of one activity (or a set of activities) depends on the completion of a preceding activity. Arrows are used to indicate the direction of the activity flow. For some of the vertical lines the absence of arrows indicates that information flows both upward and downward.

A variety of symbols has been used in Figure 5 to provide highly visible indications of the nature of the various activities. The definitions of the symbols follow:



Each of the five principal categories is discussed separately in the following section of the report. Interfaces among the five principal categories are described at appropriate places in the text.

3.3.1 Major Decisions and Milestones.

The major decisions and major milestones for the space disposal program are shown in the dashed box in the middle of Figure 5. The first major decision is assumed to take place in 1980 in order to provide initial funding

for space augmented disposal of military HLW. In the diagram this decision is designated by the number 1 to the lower right of the decision diamond shaped symbol. Clearly, if this decision is not favorable, then only the terrestrial disposal options are possible. It should be noted that if this decision or any major decision is delayed beyond the dates shown, then the entire program slips. In parallel with the decision making process, it is assumed that the preparation of a draft generic EIS (DGEIS) on HLW waste disposal methods (#33) continues. During the formulation and preparation of the Draft EIS, it appears that the process should be conducted in a very open manner. Special efforts should be made to ensure active and extensive participation of the states, affected local governments and the general public. Such an open policy may cause some delays; however, it would tend to allow legitimate issues to be surfaced and resolved in a publicly acceptable manner. We believe that such an open approach would increase the confidence of the general public in the space augmentation option for nuclear waste disposal. This open approach has been recommended previously (Ref. 4). The trend of the governmental institutions involved appears to be in this direction. EPA's series of public workshops and DOE's public forums are certainly steps in this direction. Referring back to Box #33 of the chart, a set of parallel activities is shown after completion of the Draft GEIS in 1980. This schedule for the DGEIS may be viewed as somewhat pessimistic; however, in view of past slippages we choose a more conservative date rather than 1979. Assuming that the comments on the Draft do not reveal any fundamentally serious problems, the draft could be finalized within two years (#34).

Following a yes from #1, a joint NASA/DOE concept definition study for space disposal is prepared and finalized in 1981 (#35). Following this, a joint NASA/DOE Draft GEIS on space augmentation of military HLW disposal is prepared and then issued in 1982. (#36) Based generally on the progress of the program and particularly on whether or not the development of the required new technology for chemical extraction is considered to affect the administrations anti-proliferation policy, a presidential/congressional decision is made. Figure 5 shows this decision being made in 1983 (#37). A no decision is equivalent to ending, or at least significantly slowing, the space disposal program.

The next major milestone shown is the finalization of the GEIS on space isolation of military HLW in 1984 (#38). Upon completion of the space GEIS, the Congress and the President could make an interim evaluation of the progress of the space disposal program to decide whether or not to approve a further block of funding for these activities. If, at this time, the uncertainties associated with the geological disposal concepts appeared to be decreasing at a sufficiently rapid rate, the space disposal program could be delayed and funded at a lower level. On the other hand, if these uncertainties were not judged to be decreasing at a sufficient rate, or if the attitudes of the States toward disposal of HLW in their states continued to be negative, then the next phase of the space disposal program could be approved. Assuming a favorable decision, NASA paper studies are prepared which culminate in an EIS on the entire space isolation system (#40). Sufficient information about the space system is assumed to be available by 1987 for formal and informal approvals by the international community, the Federal Government, the State governments and affected local governments (#41). Assuming these approvals are obtained and that the program proceeds as shown, the complete system for space augmented

disposal of military HLW could be operational in the year 2000. (#42)

Now that the "Major Decisions and Major Milestones" category has been described in some detail, it is appropriate to describe the other four major categories shown in Figure 5.

3.3.2 Waste Retrieval System

The principal activities leading to an operational waste retrieval system are shown in the dashed-in box at the top of Figure 5. After a favorable initial presidential/congressional funding decision on space augmented disposal of military HLW (#1), DOE initiates and completes a concept definition study for a military HLW waste retrieval system (#2) in 1980. The chart indicates that NRC drafts criteria and regulations for military waste retrieval system (#3) by 1982. NRC's jurisdiction in this area is presently unclear. This question has been examined previously (Reference 4, page 29).

> "... it is interesting to note that ERDA is regulating itself in the areas of temporary storage treatment. According to Willrich, '... this type of ERDA self-regulation is specifically authorized by the Atomic Energy Act of 1954. This approach may be justifiable on national security grounds in part.'"
>
> "The Energy Reorganization Act of 1974 provides NRC the authority to license only certain ERDA facilities: (emphasis added)
>
> '... Retrievable surface storage facilities and other facilities authorized for the express purpose of subsequent long-term storage of high-level radioactive waste generated by the Administration, which is not used for or are part of, research and development activities.'"

However, an NRC operating license is required for the actual disposal of HLW in space (#42). Since an NRC license is ultimately required, it is desirable to have NRC become deeply involved in the program at an early time in order to minimize costly misunderstandings and other problems at the time of final licensing. We have addressed this issue previously in our report to the President's Science Advisor (Ref. 4, p. 36).

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

of the national high-level waste management program. Hence, we conclude that NRC should have regulatory control over siting and construction of high-level waste repositories for both commercial and military waste."

We believe that similar reasoning applies to disposal of military HLW in space.

Thus, we have assumed that NRC will have jurisdiction in this type of matter; hence, NRC is shown as developing criteria and regulations for the military HLW waste retrieval system (#3). In parallel with NRC's draft criteria and regulations for military waste retrieval, DOE performs R&D on the waste retrieval system (#4) including initial experiments on Waste retrieval (#5).

After completion of these preliminary activities, DOE has sufficient information to formulate a program definition of the waste retrieval system (#7) in 1983. By 1984 DOE is shown as completing the design of the waste retrieval system (#8). In parallel with this design activity, DOE initiates the process to develop an EIS for the waste retrieval system (#9). NRC finalized the criteria and regulations for the waste retrieval system (#6) in 1984. NRC is then in a position to consider DOE's application for a construction permit. (It should be noted that DOE is currently not required to obtain an NRC construction permit for this type of activity). After NRC grants the construction permit (#10), DOE completes the building of the waste retrieval system (#11) in 1989. Next, NRC grants an operating license (#12) and DOE initiates operation of the waste retrieval facility (or facilities) in 1990 (#13). This completes the description of the activities involved in producing an operational Waste Retrieval System. Next, we consider the activities and events associated with the development and operation of a chemical extraction facility.

3.3.3 Chemical Extraction and Solidification Systems

The principal activities leading to an operational chemical extraction and waste solidification facility are shown in the next lower dashed-in box in Figure 5. The development of a chemical extraction system is required for space augmented disposal of military HLW because of the excessive weight and energy required to dispose of all the military HLW in space. Subsequent to initial funding for space disposal (#1), DOE evaluates chemical extraction requirements for space isolation (#14). This evaluation influences the draft GEIS on space isolation (#36). Based on these evaluations and the progress in other programmatic areas, the executive and congressional branches of the government will decide whether or not to approve further funding for chemical extraction for space isolation (#37). A possibly sensitive issue involved in this decision is whether or not the development of a new technology for chemical extraction would be considered to increase the danger of nuclear proliferation, especially if plutonium were separated from the fission products. If presidential/congressional approval is obtained, then DOE proceeds to perform R&D on the chemical extraction processes and system (#15). Based on both the information gained during this R&D and prior information, DOE develops a program definition for the chemical extraction system (#17). Next, DOE proceeds to design a facility for chemical extraction of the components of the military HLW that are to be sent to space (#18), and to develop draft and

final EIS's for this facility (#19). In parallel with these activities, NRC finalizes its criteria and regulations for chemical extraction for space disposal (#16). NRC is then ready to consider DOE's application for a construction permit for the chemical extraction facility (#20). (This step may not be required). After the NRC construction permit is received, DOE builds the chemical extraction facility (#21). Next, DOE applies for an NRC operating license. (This step may not be necessary). Once the NRC license is received (#22), the plant is ready for operation (#23). It has been estimated that this facility could be operating in 1991.

The HLW waste from the waste retrieval facility (#13) is then transferred to the chemical extraction facility (#23) for removal of the components of military HLW that are to be disposed of in space. Co-location of the waste removal system and the chemical extraction facility would minimize the efforts required for the transfer of the space-bound waste. The assumption has been made that these components are in a liquid form. Hence, it is necessary to have a facility to convert them to a solid. However, if the process used in the chemical extraction facility produces these components in a solidified form, then a separate solidification facility would not be required. This, in effect, combines the chemical extraction facility and the solidification facility. Such an approach would decrease the number of EIS's, construction permits, and operating licenses by a factor of two. However, the information content would effectively be the same.

The flow of activities leading to the operation of a space-bound waste solidification facility (#32) is essentially identical to that shown for the chemical extraction facility, hence, it is not discussed here. However, it should be pointed out that the chart is based on the assumptions shown in the asterisk accompanying box #24, that interim storage facilities and shipping casks are assumed to be designed, demonstrated and fabricated during the time that the chemical extraction facility and the solidification facility are being developed.

Now that the DOE systems for waste retrieval, chemical separation and solidification have been described, it is appropriate to examine both NASA's activities in developing the space disposal system, and potential influence of both EPA and NRC on these developments.

3.3.4 Space Standards, Criteria and Regulations

The fourth major chart category - "Space Standards, Criteria and Regulations" is shown in the lower left dashed-in portion of Figure 5. Following the joint NASA/DOE concept definition study for space disposal (#35) in 1981, it is assumed that NRC would be required to develop space specific draft siting criteria (#43), and components of military HLW (#45). These criteria would presumably include items such as:

- launch site
- ascent trajectories
- low Earth orbit activities, and
- final destination and stability

In parallel, EPA is shown as developing numerical environmental standards for the space isolation system (#47). This may not be an additional requirement for EPA if the numerical standards for HLW disposal that are currently being formulated are broad enough to apply to the space augmentation option. Presumably, the EPA space disposal standards would include short-term considerations that could be applied to low probability events such as explosions on the launch pad, or an abort which caused the HLW package to land in the ocean. The EPA environmental standard for space isolation is shown as complete in 1983. EPA is apparently having difficulties in formulating strategies to cope with the long-term nature of geological waste disposal. (Ref. 6) It may be easier for EPA to write a space disposal specific standard because of the short-term risk nature of the space option. It is assumed that in 1984, NRC releases the final report on the space military HLW performance criteria and regulations (#48). These EPA and NRC requirements will impact the NASA program for development of the space disposal system. These interfaces are discussed next.

3.3.5 Space Disposal System Development

The fifth and final major chart category, "Space Disposal System Development," is outlined in the dashed-in box located in the lower right portion of Figure 5.

Box #49 represents R&D activities required to develop a storage facility for the HLW space package at the launch site. In addition, it represents the activities needed to acquire capability to assemble the HLW package including the "cocoon" containing the reentry heat shield, mechanical containment, gamma ray shielding, etc. Box #51 shows that R&D activities are required to develop a payload preparation and checkout system. This checkout would include checks prior to and post insertion of the payload into the shuttle. Box #50 indicates the preliminary design activities required to understand and develop concepts for the transportation system which takes the shuttle payload (including HLW package) from the spaceport packaging facility and transports it to the shuttle launch pad. This transportation system would include the necessary facilities for loading the complete payload into the shuttle.

In parallel with these activities, concepts for the complete space disposal mission operations would be developed for all phases of the space isolation activities (#52). R&D would be performed to examine the shuttle transportation system to determine the types of system modifications that would be required for the space waste isolation mission (#53). Perhaps some initial experiments could be performed at the Kennedy launch site in order to do cold testing of simulated payloads (#54). In addition, some preliminary R&D tests of the portions of the projected recovery system could be made (#55). The recovery system would be designed to perform recovery of the waste package from either launch abort or difficulties encountered in near-Earth space. In addition, the retrieval system would be designed to either correct the trajectory, or safely return the waste package to Earth in the event of a failure between LEO and the desired heliocentric orbit. These R&D activities would lead to sufficient increases of understanding of the interactions of the above system components to allow a program definition phase of activity to start. During this phase, the following program definition activities will be

developed:

- Launch site storage and packaging (#56)
- Payload transportation and preparation (#57)
- Shuttle transportation system and mission operations (#58)
- Recovery system (#59)

These activities complete the NASA program definition phase. In order to proceed to activities involving launch site selection and preparation of specific space related EIS, the chart indicates that it is first necessary to obtain the presidential/congressional approval indicated in box #39.

Once this presidential/congressional approval has been obtained, several alternate launch sites could be selected (#60) and a set of draft specific EIS's could be prepared by NASA on the following subjects:

- Launch site (#61)
- Payload preparation and transportation (#62)
- Shuttle High level waste operations (#63)
- Recovery System (#64)

These draft EIS's would be reviewed through the normal NEPA process. This process includes review by many contributing agencies and coordination by the President's Council on Environmental Quality (CEQ). The chart emphasizes NRC's importance in this process (#65, 66, 67, 68) because additional informal NRC reviews may be desirable during the preparation of these draft EISs since NRC is the licensing agency.

As part of the EIS process, comments on the draft EISs will be received. Some of these comments may indicate problems whose solution may require design changes. These changes are incorporated into the design to produce final designs (#69, 70, 71, 72). These final designs are included in the final EIS (#73, 74, 75, 76). A somewhat conceptually simpler approach could be used for the space specific EISs on launch site, payload preparation and transportation, operations and recovery system. These could be combined into a single EIS which would significantly reduce the number of drafts, reviews, hearings, etc. However, this reduction would be accompanied by an increase in complexity for each draft, review hearings, etc. NASA would have to make a judgment on the relative merits of these distinct approaches. If the latter approach were taken, then the EIS on the Space Isolation system (#40) would be a duplication of effort and would be eliminated.

Upon completion of the space system set of specific EISs, NASA could apply to NRC for construction permits for the launch sites (#77) and the payload preparation and transportation system (#78). It is not clear whether NRC can require NASA to apply for these construction permits under the current law. NASA may be legally allowed to construct these facilities without these licenses (Ref. 4, pg. 25). Furthermore, once they are constructed NASA may be able to operate some of these facilities (#89, 90) without an NRC operating license (#85, 86) since the waste is of military origin.

Returning to the lower right corner of the chart to the EISs on Shuttle Transportation System (STS) HLW operations (#75) and the recovery system (#76),

the chart shows that NRC demonstration permits (#79, 80) are obtained prior to cold testing, i.e., demonstrating the STS operations system and the simulated HLW package recovery system. Prior to the actual demonstrations, the scope of the demonstrations (#84) would presumably be agreed upon by DOE/NASA/NRC. Whether actual recovery of simulated waste packages would be required from both the deep ocean floor and also from an imperfect 0.86 AU heliocentric orbit is not clear at this time. Following these "cold test" demonstrations, NRC operating licenses are obtained for operation of both the Shuttle HLW system (#87) and the recovery system (#88). With the delivery of the portion of the military HLW that is to be sent to space (#32), the complete demonstrations could be completed in 1999. If this occurred, the NASA/DOE system for space augmentation of selected components of military high-level waste could be operational in the year 2,000.

3.4 SUMMARY OF LOGIC

The approach described above for space augmentation of military HLW disposal allows for major funding decision points on 1980, 1983, 1984, 1987. The assumption has been made that the geologic HLW disposal program proceeds in parallel with the space disposal program. If progress on geologic disposal of HLW is sufficiently promising, then there are several logical decisions points at which the emphasis on space disposal can be decreased. On the other hand, if serious delays are encountered in the geologic disposal program, the space option could be accelerated at these decision nodes. Thus, the approach presented here provides the decision makers with adequate flexibility.

CHAPTER 3

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