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EXTRATERRESTRIAL DISPOSAL OF NUCLEAR WASTES

RADIOACTIVE WASTE

KEYWORDS: *space, radioactive waste disposal, transuranium elements, launching, safety, rockets, capsules, economics*

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If a stable non-Earth intercept trajectory or orbit can be assured, extraterrestrial disposal offers the complete removal of long-lived nuclear waste constituents from Earth. The primary unfavorable features are that the concept deals with only part of the waste; possible launch safety problems exist, retrievability and monitoring are difficult, and the concept will require international agreements.

Extraterrestrial disposal of the total waste constituents and of only the transuranic elements were considered. However, space disposal of the transuranics only is believed to be the most practical scheme, primarily because of the very high space transport cost per unit of weight.

The implementation of space disposal of transuranic waste could be achieved with current technology. This technology is considered to include the space shuttle and the space tug, advanced vehicles that use existing engineering technology.

The safety aspects for space disposal primarily include safety during launch and control of the extraterrestrial destination of the waste constituents. The potential for an abort that could cause a release of radionuclides during any one space launching is modestly high; however, relatively small amounts of waste constituents are associated with each launch; and package integrity is high even in an abort.

The major energy consumption in space disposal is for propelling the waste to its final destination. This energy consumption for disposal of actinide waste is about 4 to 5 orders of magnitude less than the electrical energy from the original nuclear fuel, depending on the final space destination.

INTRODUCTION

This paper is extracted essentially verbatim from Vol. 1 of Ref. 1, which is part of an extensive analysis by numerous contributors of several waste management alternatives.

If a stable non-Earth intercept trajectory or orbit can be assured, extraterrestrial disposal offers the complete removal of long-lived nuclear waste constituents from the Earth and the potential for an international solution to waste management. The primary unfavorable features are that the concept deals with only part of the waste, possible launch safety problems exist, retrievability and monitoring, if necessary, are difficult, and the concept will require international agreements.

Extraterrestrial disposal of the total waste constituents and of only the transuranic elements were considered. However, space disposal of the transuranics only is believed to be the most practical scheme, primarily because of the very high space transport cost per unit of weight (at least $2000/kg of waste material). Because of the high shielding weight and cooling systems required for space disposal of the total high-level waste, disposal of transuranic element waste separated from the other waste constituents received primary emphasis and is used as the base case in this study. The remaining waste must be disposed of by some other means.

WASTE MANAGEMENT SYSTEM

The overall waste management system, shown in Fig. 1, consists of likely interim aqueous waste storage to allow for decay and simplification of partitioning followed by:

1. partitioning of the aqueous waste into a transuranic element fraction contaminated

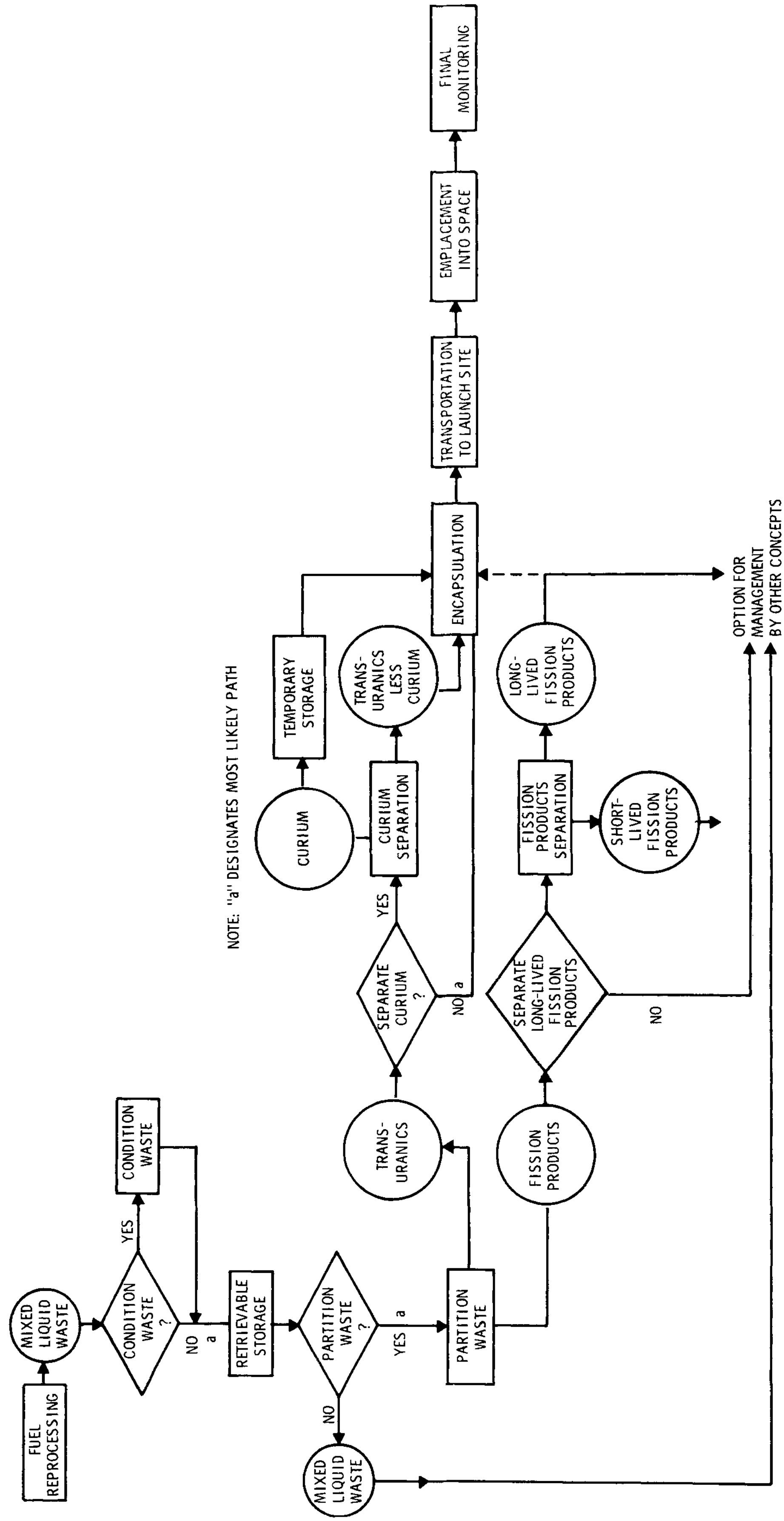

Fig. 1. System requirements for managing high-level radioactive waste by extraterrestrial disposal.

by no more than 1% of the fission products and the remaining waste which must be disposed of by an alternative method

2. converting the actinide waste at the reprocessing plant to a refractory oxide and encapsulating this into high-integrity multiple-barrier capsules
3. transporting the capsules overland to a space launch site
4. launching the waste into space to an initial low-Earth orbit with a reusable space shuttle, followed by space tug transport to the final destination
5. monitoring for control to destinations and for off-standard events and radioactivity in the upper atmosphere.

SPACE FLIGHT

The launch deployment sequence using a shuttle and a tug is shown in Fig. 2. The discussion on space flight is based on analyses by NASA Lewis Research Center.[2] Typically, the shuttle is first launched into a low circular Earth orbit (150 to 500 km above the Earth). From this orbit, the tugs or upper stage(s) are launched to carry the waste package to its final destination. In some cases, the launch system can project the waste to its final destination without subsequent course correction. In other cases, the waste tug will require subsequent mid-course corrections or propulsion.

The implementation of space disposal of transuranic waste could be achieved with current technology. This technology is considered to include the space shuttle and the space tug, advanced vehicles that use existing engineering technology.

Some consideration was given to potential advanced space propulsion systems, such as solar sails,[3] nuclear propulsion, ion propulsion,[4] and acceleration of waste particles electrically from an orbiting platform.[5] Advantages appear possible with most of these advanced schemes in regard to more flexibility in achieving destinations, larger

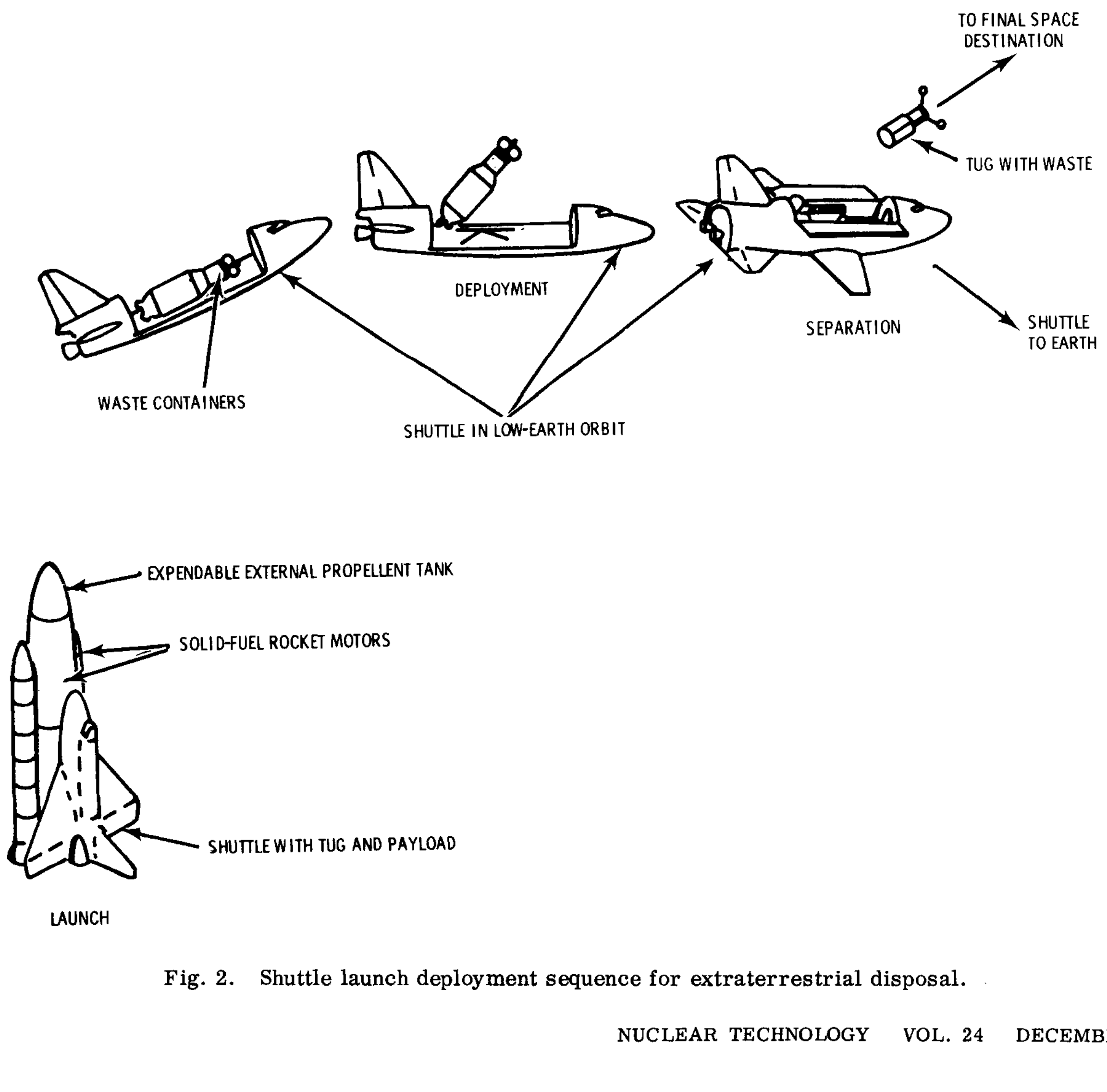

Fig. 2. Shuttle launch deployment sequence for extraterrestrial disposal.

payload, or improved flight economics. However, they are undefined and insufficiently advanced to permit the analysis required by this study.

Space trajectories considered include the following:

1. solar system escape
2. solar impact
3. a high-Earth orbit on the order of 100 000 miles (160 000 km)
4. a solar orbit other than that of the Earth and other planets.

Information on these destinations is shown in Table I.

TABLE I

Summary of Potential Space Destinations

Destination	Delta-V[a] (km/sec)	Advantages	Disadvantages
High-Earth orbit	4.11	low Delta-V launch any day passive waste package can be retrieved	long-term container integrity required orbit lifetime not proven
Solar orbits via			
Single burn beyond Earth escape	3.65	low Delta-V launch any day passive waste package	long-term container integrity required Earth re-encounter possible (may not be able to prove otherwise) abort gap past Earth escape velocity[b]
Circular solar orbit	4.11	low Delta-V launch any day	long-term container integrity required orbit stability not proven abort gap past Earth escape velocity[b]
Venus or Mars swingby	4.11	low Delta-V	long-term container integrity required limited launch opportunity (3 to 4 mo every 19 to 24 mo) requires mid-course systems need space propulsion or have possibility of unplanned encounter
Solar system escape:			
direct	8.75	launch any day passive waste package removed from solar system	high Delta-V abort gap past Earth escape velocity[b]
via Jupiter swingby	7.01	removed from solar system	high Delta-V limited launch opportunity (2 to 3 mo every 13 mo) requires mid-course systems abort gap past Earth escape velocity[b]
Solar impact:			
direct	24.08	package destroyed launch any day passive waste package	extremely high Delta-V abort gap past Earth escape velocity[b]
via Jupiter swingby	7.62	package destroyed	high Delta-V limited launch opportunity (1 to 2 mo every 13 mo) requires mid-course systems abort gap past Earth escape velocity[b]

[a]Delta-V is the incremental velocity required to leave a low-Earth orbit and is a direct indication of the size and propulsion energy of the rockets required.

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

Solar system escape can be achieved directly by a single propulsion burn from the low-Earth orbit with all propulsion and guidance provided by the launch vehicle. Solar system escape can be achieved with somewhat less energy expenditure by a properly designed swingby of Jupiter, using a single propulsion phase (tug) from low-Earth orbit. However, either case requires multiple shuttles per waste package to supply the necessary sequential propulsion energy.

Direct solar impact with a single propulsion phase would require vehicles using advanced technology. Solar impact can be achieved by a swingby of Jupiter, using a single tug phase from low-Earth orbit. However, the complexities of course control in a swingby mission may make this mission impractical.

For high-Earth orbit, the tug first places the payload into an elliptical orbit. Another tug places the payload into the final circular orbit. The stability of the high-Earth orbit cannot currently be assured for times greater than a few thousand years. Furthermore, the orbiting destinations are currently believed to require that the capsule integrity be maintained for time periods approaching those of the need for isolation from man, because waste released in Earth orbit could return to the Earth.

Solar orbit possibilities include the following:

1. orbits closely associated with the Earth's orbit by injecting the waste to Earth escape velocity or slightly beyond
2. circular orbits slightly inside or outside the Earth's orbit, achieved by additional propulsion after escaping the Earth
3. solar orbits achievable by swingby of Mars or Venus.

However, solar orbits, like high-Earth orbits, cannot yet be assured stable enough that the waste could not impact the Earth before radioactive decay is complete.

Use of the moon as a repository was not analyzed in this study because of future scientific interest, future potential value, and space environmental considerations.

The destination considered most likely is direct solar system escape. About 190 kg of transuranic waste can be transported in each flight to direct solar system escape with the proposed space vehicles. This capacity provides for the disposal of the transuranics from ~280 MT of spent light-water-reactor fuel in each flight.

WASTE PACKAGING

A conceptual design of a high-integrity capsule has been developed for space disposal of waste transuranics (Fig. 3). This spherical 1.5-m-diam capsule contains transuranic oxide particles inside individual coated tungsten spheres containing a void for buildup of helium from alpha-particle decay; these spheres are within a solid aluminum

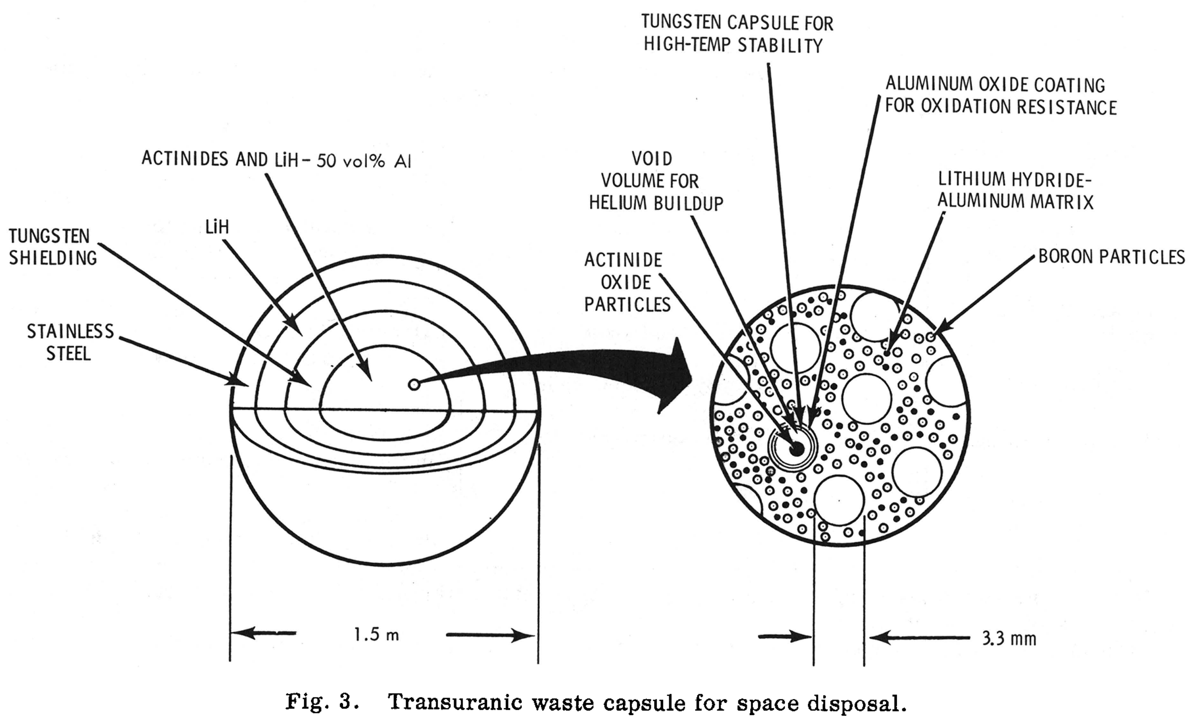

Fig. 3. Transuranic waste capsule for space disposal.

matrix that also contains lithium hydride particles for slowing down the neutrons and boron particles to absorb neutrons. These capsules can be fabricated using current technology.

SAFETY

The safety aspects for space disposal primarily include safety during launch and control of the extraterrestrial destination of the waste constituents. The potential for an abort that could cause a release of radionuclides during any one space launching is moderately high; however, relatively small amounts of waste constituents are associated with each launch, and package integrity is high even in an abort.

WASTE MANAGEMENT COSTS

The analysis of waste management costs for this and other disposal concepts was developed by taking into consideration all the necessary components of a complete waste management system. For example, the system cost includes the following:

1. any added spent fuel transport
2. interim liquid waste storage
3. waste solidification
4. interim solid waste storage
5. transport of solid waste canisters to the disposal site.

The cost estimates are highly preliminary, based on limited concept definition, but are believed to be sufficiently detailed to establish the general magnitude and a relative comparison of disposal costs.

Preliminary cost estimates for two of the disposal concepts are shown in Table II. The costs considered include only the costs directly related to implementing the concept; they do not include research and development costs nor any estimated external or indirect societal costs. Costs are discussed in more detail in Ref. 1. These estimates indicate that the cost for extraterrestrial solar escape disposal is less than 5% of current nuclear electric power costs.

TABLE II

Cost of Extraterrestrial Waste Disposal

	Total Waste Management System Costs Levelized Unit Charges	
Extraterrestrial Concepts	($/MT Reprocessed)	[mill/(kW h)]
1. Solar and Earth orbits	40 000	0.15
2. Solar escape	90 000	0.34

RESEARCH AND DEVELOPMENT REQUIREMENTS

The research and development required for extraterrestrial waste disposal include waste partitioning, waste capsule materials and form development, encapsulation process development, handling techniques, disposal trajectory studies, special instrumentation, and safety evaluations.

Estimated research and development costs of $50 million for space disposal of transuranic element waste include all costs except those for the basic flight vehicles and their auxiliaries. Overall flight development costs, expected to be many millions of dollars, are assumed to be part of the space development program conducted by government agencies other than the U.S. Atomic Energy Commission. Costs for space vehicle and trajectory development specific to waste disposal are estimated by the Pacific Northwest Laboratory to be in the range of $100 million. An additional $50 million of research and development is assumed to be needed for terrestrial disposal of the waste fraction not sent to space. This cost is the minimum estimated for terrestrial disposal concepts. Thus, the total direct research and development costs for space disposal are estimated at about $200 million.

TIMING

The timing for routine operation of space disposal, estimated at about 20 years, is controlled largely by the schedule for development and achievement of reliable operational status of the basic space shuttles and tugs by other government agencies.

ENVIRONMENTAL CONSIDERATIONS

Extraterrestrial launches of transuranic elements entail some environmental impact. Probably the most severe of these is the noise level during launch and re-entry of the shuttle. Sonic booms with overpressures of ~0.014 atm over the ocean and 0.001 atm over land can be anticipated. The ground transportation impact will be considerably greater from the large launch components than from the "payload" capsules for the launches required each year. Another launch site comparable to the existing Kennedy Space Center will ultimately be required. The environmental effects from the launch operations will be only part of the total, since the remaining waste will have to be disposed of by some other method.

ENERGY REQUIREMENT

The major energy consumption in space disposal is for propelling the waste to its final destination. This energy consumption for disposal of transuranic waste is about 4 to 5 orders of magnitude less than the electrical energy from the original nuclear fuel, depending on the final space destination.

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