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SUMMARY OF THE STUDY OF DISPOSAL OF NUCLEAR WASTE INTO SPACE

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ABSTRACT

NASA, at the request of the AEC, is conducting a preliminary study to determine the feasibility of disposing of nuclear waste material into space. The study has indicated that the Space Shuttle together with expendable and non-expendable orbital stages such as the Space Tug or Centaur can safety dispose of waste material by ejecting it from the solar system. (No launching system that is under development or planned can deposit waste material directly into the Sun.) The safety problems associated with all phases of launching and operation (normal, emergency and accident) of such a system are being examined. From the preliminary study it appears that solutions can be found that should make the risks acceptable when compared to the benefits to be obtained from the disposal of the nuclear waste. The techniques proposed to make such a system acceptable need to be carefully verified by further study and experiment. Even though more than one hundred shuttle launches would be required per year by the year 2000, the cost to the consumer would be less than five percent of his electric bill. Tests of models of waste packages impacted on reinforced concrete and soil have demonstrated the feasibility of safely containing waste material at impact speeds up to 1050 feet per second.

INTRODUCTION

In order to meet the demand for electrical energy, the U.S. will be counting heavily on nuclear powerplants. The Atomic Energy Commission projects that by 1990 the U.S. will need the equivalent of almost 400 nuclear powerplants of 1000 MWe capacity each (see fig. 1 and ref. 1). Extrapolating to the year 2000 doubles the number.

A key issue is how to dispose of the large quantity of radioactive waste materials that will be produced. The group of radioactive wastes most difficult to handle is the actinides. These are the isotopes generated by transmutation of isotopes of the heavy elements (atomic weights in the range of 227 and higher). Compared to most of the fission products, they have exceedingly long half-lives and human beings are very sensitive to them.

If they are ingested into the human body, they tend to stay there and continually irradiate the person from within. In addition, because the actinides generally have half-lives of tens of thousands of years, they must be stored for hundreds of thousands of years before they decay to levels safe enough that release to the biosphere can be tolerated.

The amount of actinides generated each year by a typical 1000 MWe nuclear powerplant is 30 kilograms (see fig. 2). If they are stored for ten years, the residue is about 72,000 curies* of radioactivity (ref. 1). A human being in a lifetime can safely tolerate amounts like 0.04 to 30 microcuries (millionths of a curie) (ref. 2). This means that one 1000 MWe reactor produces somewhere between a billion and a trillion allowable life-time ingestion doses each year.

The reason for the extraordinary safety practices that has become a trademark of the nuclear power industry is apparent. The unparalleled safety record of nuclear industry gives testimony to the dramatic success of the safety practices that have been enforced.

An additional characteristic of radioactive materials is that they generate heat while they decay. One year's worth of actinides from a 1000 MWe powerplant produces about 2 kW of heat. This is a factor that must also be considered in the design of systems for handling of radioactive waste materials.

As stated earlier, there will be hundreds of nuclear powerplants of the equivalent of 1000 MWe each in operation after 1980. The total number of allowable life-time ingestion doses of actinides produced each year from all of these plants is of the order of thousands to

*One curie is about the rate of radioactive disintegration of 1 gram of radium.

millions of billions (see fig. 3). Because of the long decay times, the doses generated even over centuries accumulate. By 1990 doses like a million billion times that which is allowable per person will have been generated (fig. 3). The allowable release rates to the environment must therefore be extremely small.

WASTE DISPOSAL STUDY

The AEC is currently making intensive studies of how the radioactive waste materials can best be disposed of or stored with virtually no leakage. Figure 4 lists a variety of techniques that is receiving attention. Except for transmutation for which a practical process needs to be invented, space disposal is the only technique that offers the unique potential of entirely getting rid of the material from Earth. In this case only short-term storage would be necessary on Earth.

The Atomic Energy Commission has asked NASA to study the feasibility of disposing of radioactive waste into space. A team led by Lewis Research Center was formed of experts from Ames, Johnson, and Kennedy Space Centers and also from NASA's Nuclear Safety Office and AEC's Battelle Northwest Laboratory.

Various launch vehicles including Atlas-Centaur, Saturn V, and Titan IIIE-Centaur, and the Space Shuttle were considered. In orbit, launch stages considered included expendable stages like Centaur and recoverable stages like the proposed Space Tug.

The destinations for the waste material payloads considered (ref. 3) were Earth orbit, solar orbit, solar system escape and solar impact. Earth orbits between synchronous orbit and the Moon's orbit were considered as storage locations from which the waste packages would eventually be retrieved and permanently disposed of by later generations. Solar orbits achieved by Earth escape (single burn to elliptical orbit) and also by Earth escape followed by an insertion, six months later, into a 0.9 AU orbit were studied. Analysis has not assured that packages in the elliptical orbits would never intercept Earth for the 300,000 year period needed for radioactive decay to safe levels.

Solar-system escape accomplished first by boost via the Shuttle into low-altitude Earth orbit and then by a two-stage acceleration to solar-system-escape velocity was found to be the most attractive technique because this offered the possibility of permanently getting rid of the waste material.

Solar impact (burial in the Sun), because of the high energy required, was not possible with any combination of the launch vehicles now available or planned. This technique would require a major advance in space propulsion capability, such as electric or laser propulsion.

Consideration was also given, in the case of solar-system escape and solar impact, to the use of planet swing-by trajectories. Because of the requirements for sophisticated guidance and control systems that must be operable many months after launch with both extreme accuracy and reliability and because of the launch-window requirements, swing-by trajectories are not favored.

The disposing of radioactive waste materials into space poses the problems of safety and reliability of the launching systems. Figure 5 lists some of these. There are safety problems concerned with normal, emergency, and accident situations that can occur on the launch pad, during launch, in orbit, and during orbital operations and launching to a final destination.

On the launch pad consideration has been given to launch pad accidents. These accidents could result in high over-pressure, high temperatures, and possible impact of explosion-generated fragments with the waste package. A package design evolved, after preliminary screening studies (ref. 4 and 5), that would survive all such postulated accidents.

During Earth and space launch operations, an abort or accident or emergency situation could result in the reentry of the package. The package was designed to be able to withstand a vertical reentry and a grazing reentry from Earth escape velocity. The package was designed so it would not burn up on reentry but would decelerate so that its impact velocity would be no more than about 1000 feet per second. Provisions were made in the design so that an impact at these velocities, on surfaces as hard as reinforced concrete, would not rupture the package (ref. 6).

The package has shielding built within it to reduce radiation outside it to safe allowable levels.

Disposal of the heat that is generated by the radioactive decay of the waste isotopes is provided for during all phases of the operation in normal, emergency and accident situations.

The cost of disposing of the radioactive waste safely was estimated as a major measure of feasibility. Public acceptance which involves trading of risks versus benefits for storing or disposing of fission products on Earth vs. disposing in space is difficult to determine and is recognized as a major problem but not addressed in this study. The benefits of using nuclear-generated power must be weighed against the risk of storing vast quantities of deadly radioactive waste on Earth for hundreds of thousands of years, or the risks involved in major space launch operations required to eliminate the risks involved in storage on Earth.

DESCRIPTION OF WASTE PACKAGE

A waste package conceptually designed to safely handle all the requirements discussed previously is shown in figure 6. The actinides are embedded in a matrix material. A close-up of the actinide waste and matrix material is shown in figure 7. The matrix material is an aluminum-copper matrix that provides good thermal conductivity to assist in the removal of the heat generated by the actinides without excessive internal temperature. The matrix contains lithium hydride particles. This combination of aluminum-copper matrix material with lithium hydride provides high-heat capacity and shielding against the neutrons and gamma radiation emitted by the waste. The high-heat capacity minimizes the temperature excursions that can occur during periods of poor external cooling or high external temperatures such as would occur during fires or reentry. The actinide material in the form of oxides is formed into glassy beads about one-eighth inch in diameter. A tungsten shell surrounds the beads with 15 percent void enclosed with the oxides to allow room for the helium gas generated during the decay. A moly disulfide coating inhibits oxidation of the tungsten.

Figure 6 shows two layers of radiation shielding. An inner metal layer provides a shield primarily for gamma radiation. The outer layer is composed of lithium hydride to provide neutron shielding. The shields are surrounded by an impact shell. This is a ductile shell of a material like stainless steel that will not rupture during the rapid and large deformation of the package that can occur during impact on hard objects at high speeds. This shell would probably be multi-layered to provide the best protection against rupture.

The reentry shield is composed of two layers. The outer layer is a three-dimensional weaving of silicon dioxide fibers embedded in a fused silicon-dioxide matrix. This material is designed to withstand the extremely high temperatures that occur during a 90° (perpendicular) reentry into the Earth's atmosphere from Earth escape velocity. It provides the necessary ablative protection and insulation to survive such a reentry. This outer silicon dioxide layer is backed up by a graphite reentry shell that is designed to withstand a long-duration grazing type of reentry from Earth escape velocity. The high-heat capacity and high operating temperature of graphite are essential for this kind of reentry which will cause the silicon dioxide layer to completely ablate away before the reentry is complete.

The center of gravity of the package is well forward of the center of pressure. The void between the waste-package impact shell and the backside of the outer container is filled with a light-weight, high-conductivity material like aluminum honeycomb.

Cooling for the waste package in space is provided by radiation from the outer surface of the package. During launch into orbit, while the package is still within the payload bay, cooling is provided by thermal inertia of the package and by radiation to the walls of the payload bay.

The weight breakdown of a package suitable for launch by the Space Shuttle and Tug combination to solar-system escape is shown in figure 8. The total package weighs 3250 kilograms for a waste material weight material of 200 kilograms.

SUMMARY OF LAUNCH DESTINATIONS RESULTS

The most feasible launch system was found to be the Space Shuttle (see fig. 9) operated with various tug configurations (ref. 3). The transportation costs using the Shuttle were found to be about one-half that for any of the other launch systems reviewed. A picture of the Orbiter deploying a Space Tug with a waste payload is shown in figure 10.

In order to launch the waste payload to solar-system escape velocity, two Space Shuttle launches are required, one to launch a recoverable Space Tug and the other to launch an expendable Tug stage with the payload. The recoverable Tug is mated with the expendable Tug in orbit so that the recoverable Tug acts as a first stage boost from orbit. The Tug returns to the Orbiter for return to Earth. The expendable Tug accelerates the payload to the final velocity required to achieve solar-system escape.

Figure 11 summarizes a comparison of some of the payload destinations that were considered. High Earth orbit requires a container whose integrity must be assured for long periods of times (decades or centuries) because they must be retrieved and disposed of by later generations. The decomposition of materials like hydrides could cause hydrogen embrittlement and weakening of metals by the hydrogen liberated; the internal pressure would build up due to generation of helium from the decay of the radioisotopes; and neutrons from spontaneous fission could potentially embrittle package materials; all these factors would be expected to limit the package lifetime when such very long storage times are considered. Most of the comments indicated are obvious. "Passive spacecraft" in the table refers to the fact that no subsequent burn of a propulsion system is required at some later date to assure that the destination is achieved.

The number of Space Shuttle launches required per year to get rid of the actinide group of radioactive waste is shown in figure 12 for high-Earth orbit and for solar-system-escape destinations. Launches are made ten years after the waste material has been generated. By the year 2000 about 100 launches of the Space Shuttle would be required each year for the solar system escape disposal.

COST SUMMARY

The cost of transporting the actinides group of nuclear powerplant waste material to high Earth or solar orbit or to solar system escape is shown in figure 13. The payload weights shown are the complete waste disposal package weight. The cost per kilogram shown is the cost per kilogram of total package weight. The cost to the consumer is shown in terms of mills per kW-hr and as a percent of the conumer's electric bill, the reference cost of electric to the consumer assumed to be 25 mills per kW-hr. The cost of transportation for permanently getting rid of the actinides by launching it out of the solar system is 2.5 percent of the consumer's electric bill. The additional cost of the process required to separate the actinides from the waste products so that only 0.1 or 0.01 percent of the fission products remain in the waste for space disposal is of the same order as the transportation cost. The total cost of permanently getting rid of the worst radioactive waste material is therefore only about 5 percent of the consumer's electric bill.

IMPACT EXPERIMENTS

Experiments have been conducted to demonstrate techniques for designing packages containing radioactive material that will not rupture at impact speeds up to 1100 feet per second. Figure 14 shows a two-stage rocket-sled test of a two-foot-diameter model that weighs about 500 kilograms. The first stage on the left is recovered by water-brake deceleration following separation from the second stage, which accelerates the model to its final, desired impact speed.

The second stage is destroyed by a barrier while releasing the model for impact onto a five-foot cube of heavily reinforced concrete. The results of an impact at a speed of about 1050 feet per second are shown in figure 15. The eight-ton concrete block is demolished. The model is flattened to less than 1/2 its original height. No leaks were detected in the containment vessel. Had fission products been inside, they would be safety contained after the impact. Several such tests have confirmed that the design principles to be used will result in a safe design impact survival (ref. 6).

Another impact test was conducted at Sandia to determine the effect of impact on soil (ref. 7). (See fig. 16) The test vehicle is accelerated by towlines that are pulled by a rocket sled on a track. An impact on soil at a speed of 800 feet per second resulted in a crater about six feet deep, burial of the model to a depth of 13 feet, and a dented and slightly scratched model that had no detectable leaks. (See fig. 17.)

CONCLUSIONS TO DATE

A study of the feasibility of disposing of radioactive waste material into space has resulted in the following conclusions to date:

1. The problems associated with the safe launch during normal, emergency and accident situations appear solvable. A conceptual design of a waste package that incorporates all the features necessary for achieving the reliability for such an operation has been successfully accomplished.

2. The Space Shuttle plus Tug is the most economical transportation system considered.

3. The cost of disposing of the actinide portion of the radioactive waste materials generated by nuclear powerplants would add about five percent to the cost of the consumer's electric bill.

4. By the end of this century about 100 shuttle launches will be required per year to dispose of the nuclear wastes generated.

5. Further detailed studies and experimental verification of key problem areas should be undertaken.

REFERENCES

(1) Anon: Siting of Fuel Reprocessing Plants and Waste Management Facilities. Rep. ORNL-4451, Oak Ridge National Lab., July 1970.

(2) Anon: Report of Committee II on Permissible Dose for Internal Radiation (1959) - International Commission on Radiological Protection, Pergamon Press, 1960.

(3) Zimmerman, A. V.; Thompson, R. L.; and Lubick, R. J.: Summary Report of Space Transportation and Destinations Considered for Extraterrestrial Disposal of Radioactive Waste. NASA TM X-68211, March 1973.

(4) Hyland, R. E.; Wohl, M. L.; Finnegan, P. M.; and Thompson, R. L.: Study of Extraterrestrial Disposal of Ratioactive Wastes--Part II. Preliminary Feasibility Screening Study of Extraterrestrial Disposal of

Radioactive Wastes in Concentrations, Matrix Materials, and Containers Designed for Storage on Earth. NASA TM X-68147. October 1972.

(5) Hyland, R. E.; Wohl, M. L.; and Finnegan, P. M.: Study of Extraterrestrial Disposal of Radioactive Wastes - Part III. Preliminary Feasibility Screening Study of Space Disposal of the Actinide Radioactive Wastes with 1 Percent and 0.1 Percent Fission Product Contamination. NASA TM X-68216, April 1973.

(6) Puthoff, R. L.: A 1055 ft/sec Impact Test of a Two-Foot Diameter Model Nuclear Reactor Containment System Without Fracture. NASA TM X-68103, June 1972.

(7) Puthoff, R. L.: A 810 ft/sec Soil Impact Test of a Two-Foot Diameter Model Nuclear Reactor Containment System. NASA TM X-68180. December 1972.

PROJECTED GENERATION OF NUCLEAR POWER

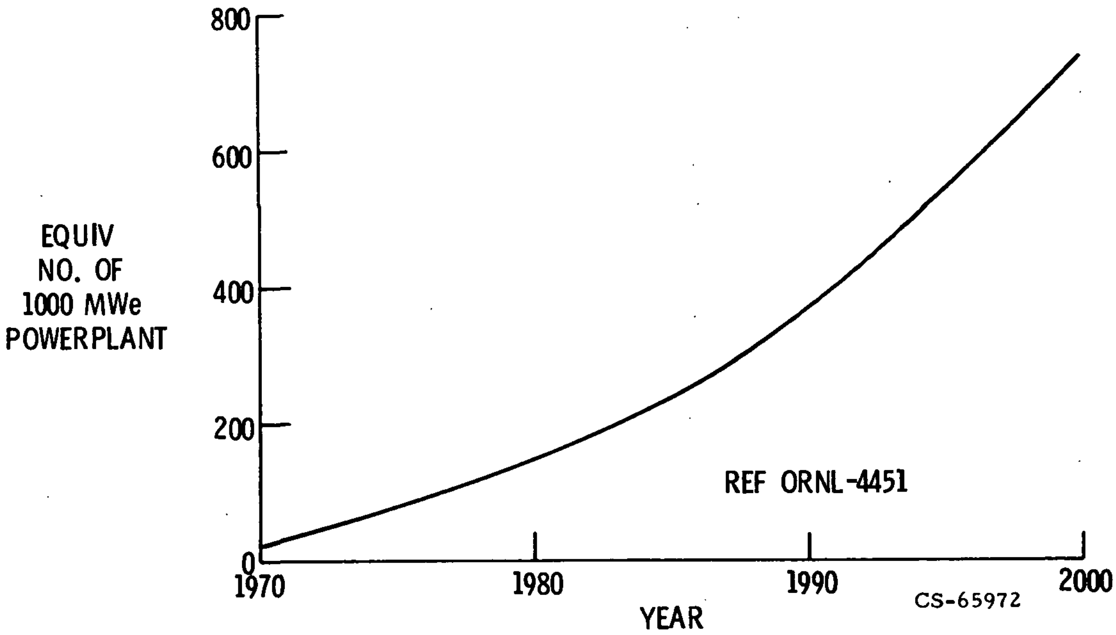

Fig. 1

WASTE ACTINIDES GENERATED/YR BY ONE
1000 MWe POWERPLANT
AFTER 10-YR STORAGE

ISOTOPES	MASS, KG	THERMAL POWER, W	RADIOACTIVITY CURIES*
NEPTUNIUM (237-239)	23	1.5	500
PLUTONIUM (236-242)	1.7	107	13 500
AMERICIUM (241-243)	4.3	193	6 000
CURIUM (242-246)	.6	1815	52 000
TOTALS	29.6	2106	72 000

*ALLOWABLE LIFETIME INGESTION 0.04 TO 30×10^{-6} CURIES. CS-65970

Fig. 2

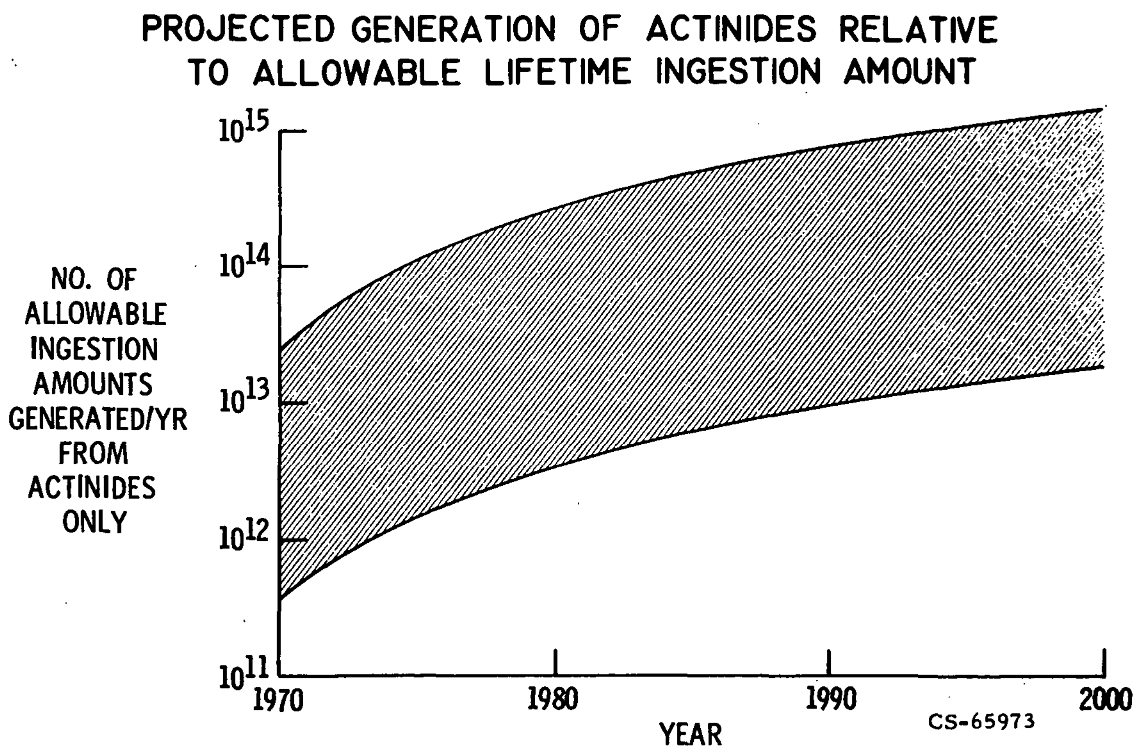

Fig. 3

CONCEPTS BEING CONSIDERED BY AEC FOR STORAGE OR DISPOSAL OF NUCLEAR WASTES

MONITORED SURFACE STORAGE IN SEALED CONTAINERS

STABLE GEOLOGIC FORMATIONS (SALT BEDS, BED ROCK)

SEA BED

ICE CAP

10-MILE DEEP HOLE

DEEP MAN MADE CAVITIES

TRANSMUTATION

SPACE DISPOSAL

CS-65965

Fig. 4

SPACE DISPOSAL PROBLEMS

SAFETY
- LAUNCH PAD
- REENTRY
- EARTH IMPACT

SHIELDING

HEAT REMOVAL
- NORMAL: PRELAUNCH, LAUNCH, SPACE
- ACCIDENT: FAILURES, REENTRY, POST IMPACT

COST

PUBLIC ACCEPTANCE

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Fig. 5

WHAT DOES A PACKAGE LOOK LIKE

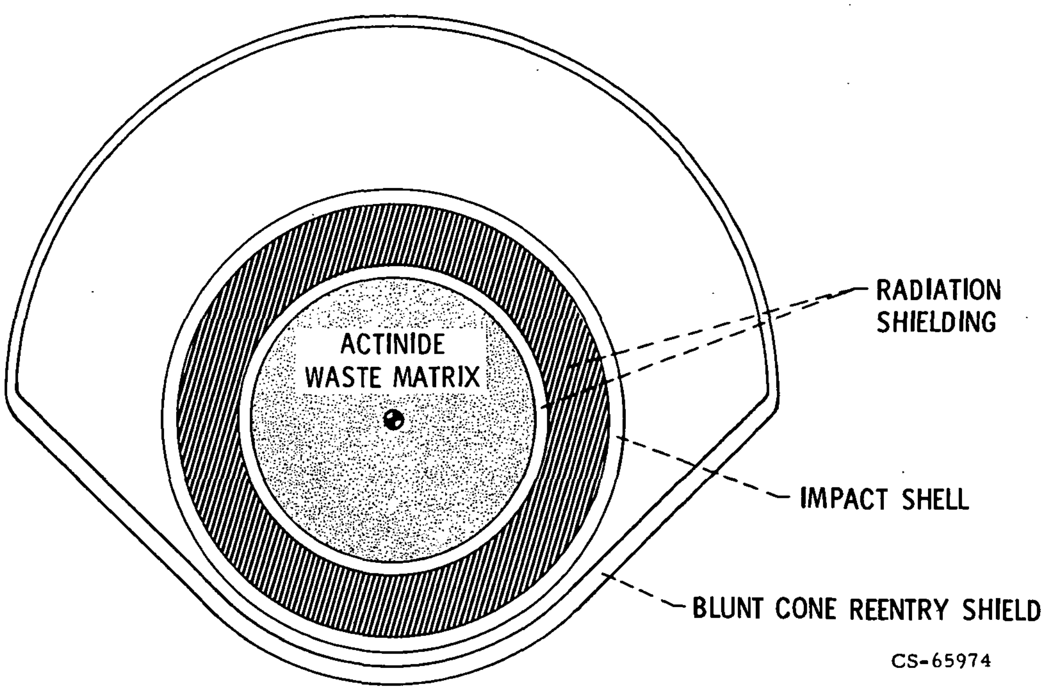

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Fig. 6

MODEL OF ACTINIDE WASTE & MATRIX

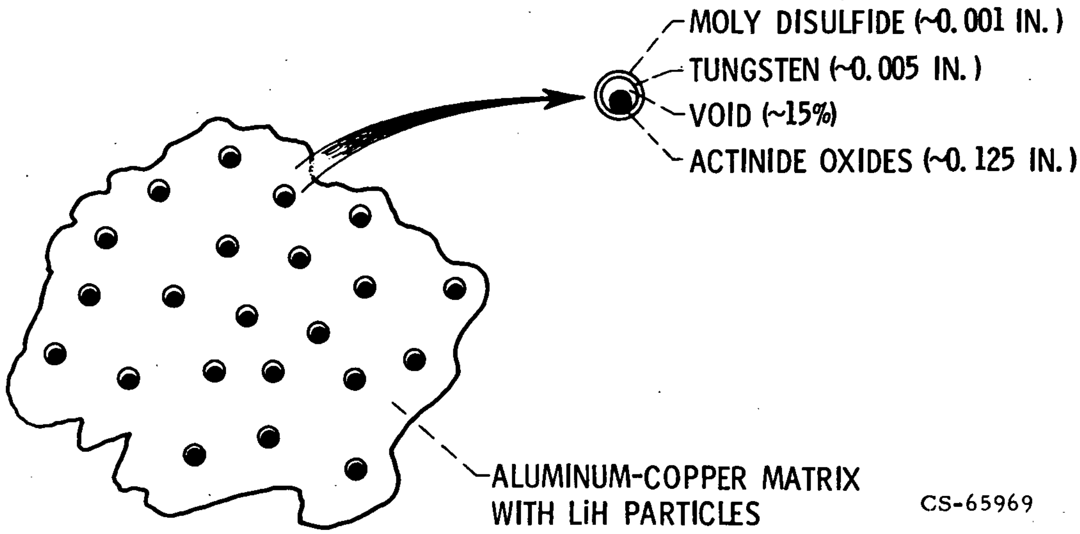

Fig. 7

TYPICAL NUCLEAR WASTE PACKAGE WEIGHT BREAKDOWN

SOLAR SYSTEM ESCAPE

COMPONENT	WEIGHT, KG
ACTINIDE WASTE	200
COPPER-ALUM, LiH MATRIX	625
TUNGSTEN, γ, SHIELD	1190
LITHIUM HYDRIDE, η, SHIELD	180
STAINLESS STEEL CONTAINMENT	640
REENTRY HEAT SHIELD	415
TOTAL	3250

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Fig. 8

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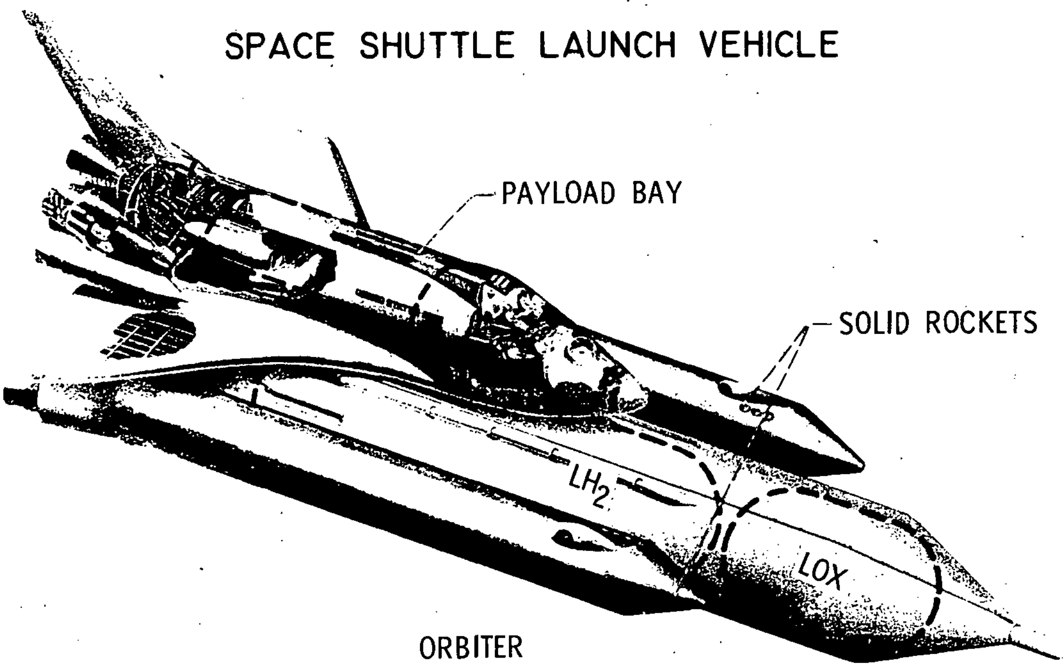

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Fig. 9

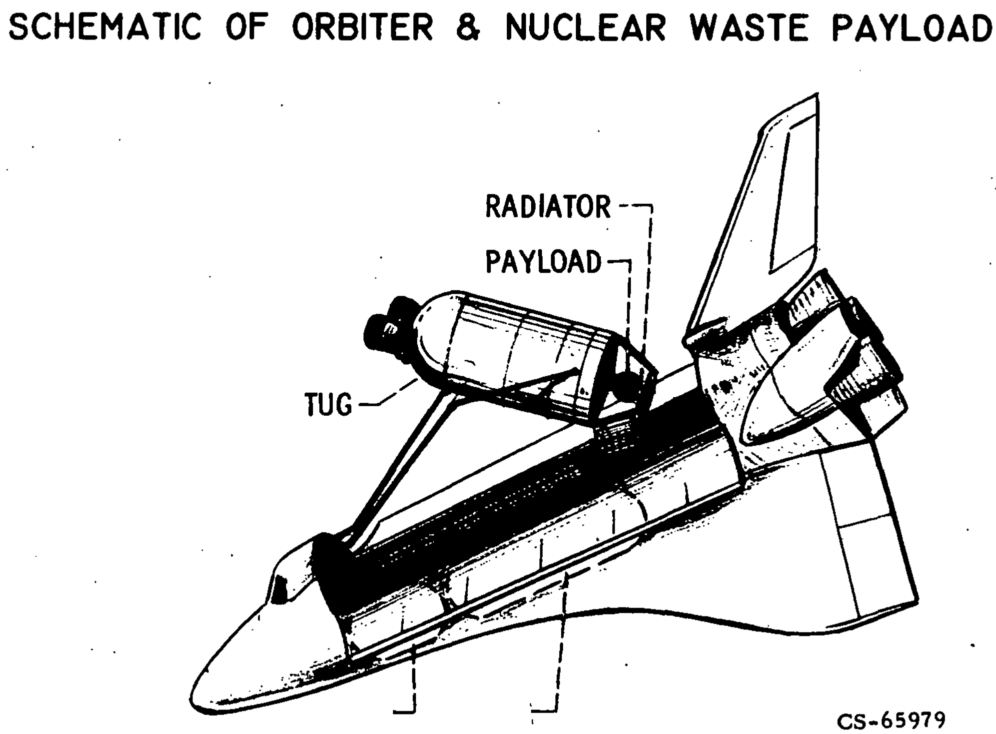

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Fig. 10

COMPARISON OF DESTINATIONS

DESTINATION	ΔV, FT/SEC	ADVANTAGES	DISADVANTAGES
HIGH EARTH ORBIT	13 500	LOW ΔV LAUNCH ANY DAY PASSIVE SPACECRAFT CAN BE RETRIEVED	CONTAINER INTEGRITY REQD ORBIT LIFETIME NOT PROVEN CLUTTER UP SPACE
SOLAR ORBIT (SINGLE BURN)	12 000	LOW ΔV LAUNCH ANY DAY PASSIVE SPACECRAFT	POSSIBLE EARTH ENCOUNTER POSSIBLE SUPERORBITAL - REENTRY
SOLAR ORBIT (0.9 AU)	13 500	LOW ΔV LAUNCH ANY DAY	ORBIT STABILITY UNPROVEN NONPASSIVE SPACECRAFT POSSIBLE SUPERORBITAL - REENTRY
SOLAR ESCAPE	28 700	LAUNCH ANY DAY PASSIVE SPACECRAFT REMOVED FROM SOLAR SYST	HIGH ΔV POSSIBLE SUPERORBITAL - REENTRY
SOLAR IMPACT	79 000	LAUNCH ANY DAY PASSIVE SPACECRAFT PACKAGE DESTROYED	EXTREME ΔV POSSIBLE SUPERORBITAL - REENTRY

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Fig. 11

NUMBER OF SHUTTLE LAUNCHES REQUIRED

ACTINIDE WASTE

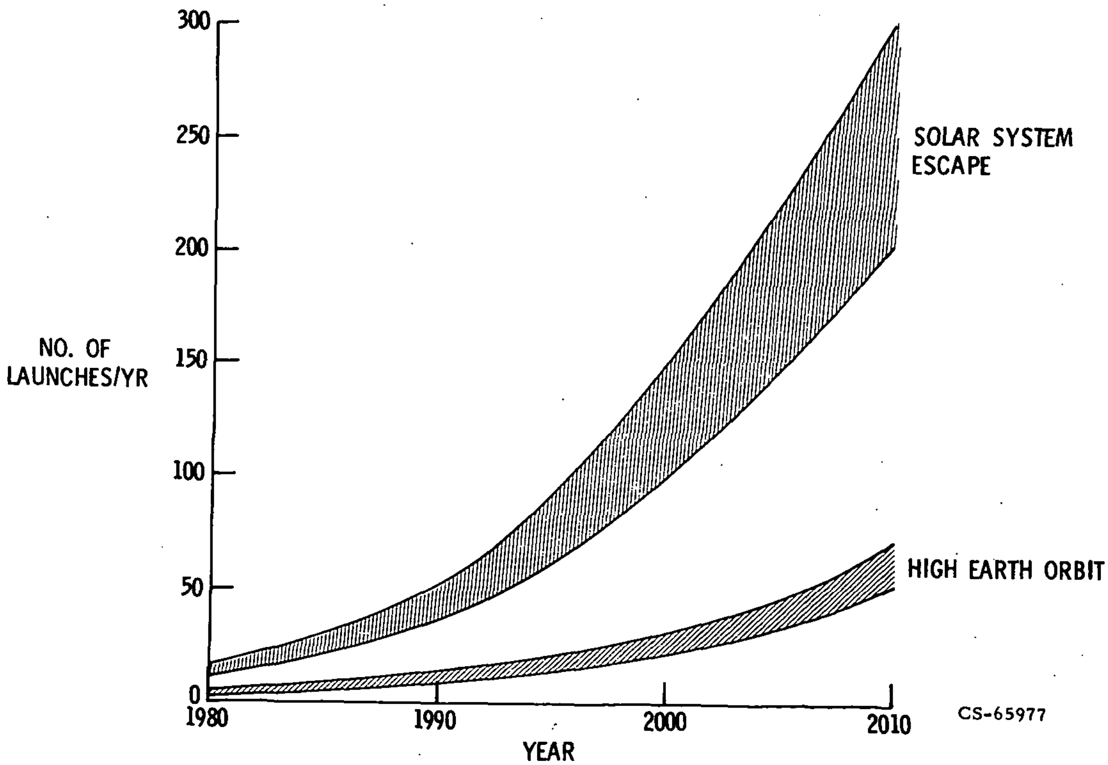

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Fig. 12

WASTE DISPOSAL COST SUMMARY
ACTINIDE WASTE

DESTINATION (VEH)	PAYLOAD, KG	COST		
		$/KG	MILLS/kW-HR	% ELEC BILL
HIGH EARTH ORBIT OR SOLAR ORBIT (SHUTTLE + TUG)	4200	2860	0.17	0.7
SOLAR SYSTEM ESCAPE (2 SHUTTLES + REUSABLE TUG + EXPENDABLE TUG)	3250	8770	.61	2.5

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Fig. 13

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IMPACT EXPERIMENTS
HOLLOMAN ROCKET SLED PICTURE

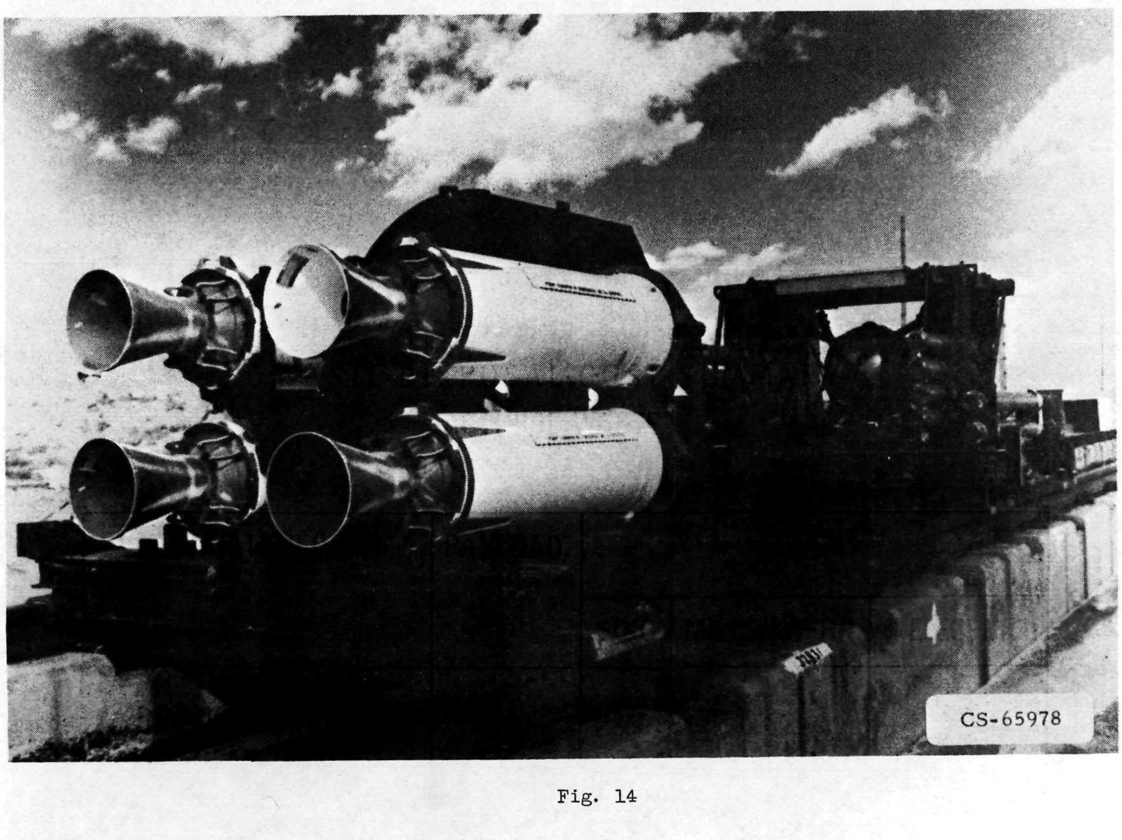
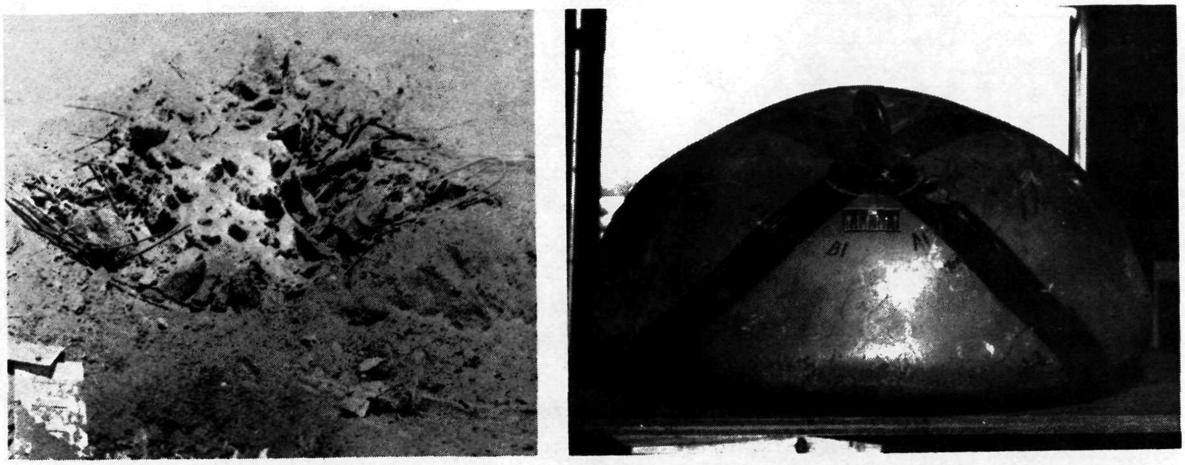


Fig. 14

RESULTS OF IMPACT EXPERIMENTS ON REINFORCED CONCRETE

1000-1100 FT/SEC IMPACT



TARGET MODEL CS-65981

Fig. 15

IMPACT EXPERIMENTS

SANDIA PULL DOWN FACILITY

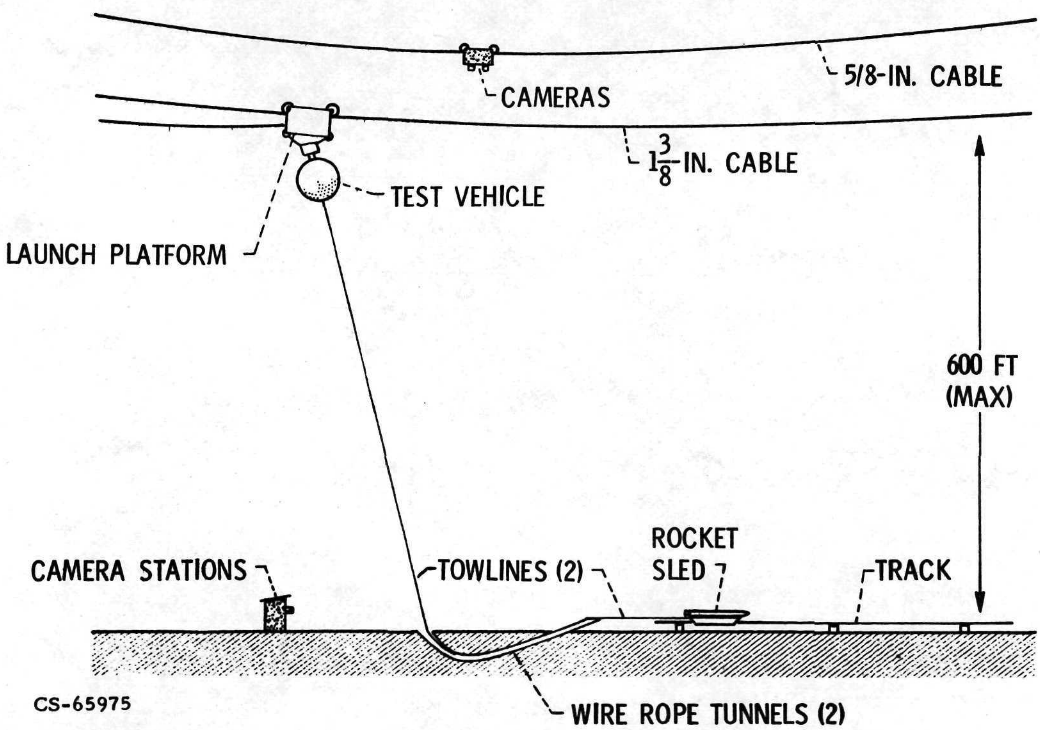


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Fig. 16

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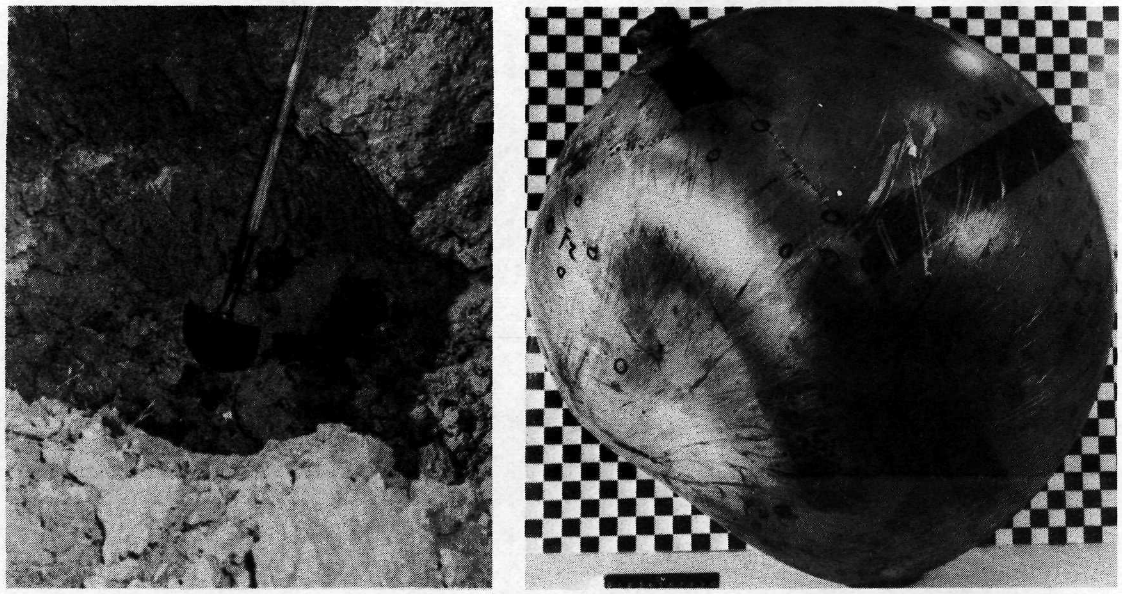
RESULT OF IMPACT EXPERIMENTS ON SOIL



CRATER MODEL CS-65982

Fig. 17

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