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AIR TRANSPORTABILITY OF REACTOR  
AND  
RADIOISOTOPE MATERIALS

by

James Fox  
Lt USAF

TECHNICAL DOCUMENTARY REPORT NO. AFWL TDR-64-81

August 1964

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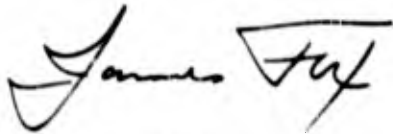
ABSTRACT

A study was made to investigate the prime considerations involved in air transportation of nuclear reactor components, radioactive wastes, and radioisotope power-generating units. The logistics, economics, and safety of supplying a remote military nuclear power plant by air and of transporting SNAP-type reactor and radioisotope auxiliary power units by USAF aircraft are explored in detail.

It was determined that such air transport operations are feasible and reasonably safe if proper planning is accomplished in the design of equipment and in the definition of mission profiles and ground handling procedures. Container criteria and procedural standards for the transport of the different categories of materiel are recommended.

PUBLICATION REVIEW

This report has been reviewed and is approved.



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## 1. INTRODUCTION

### a. Purpose

The purpose of this study is to delineate criteria and procedural standards for the air transport of reactor and radioisotope materials.

The requirement for this study was originally generated by a concern, registered by several organizations, over the lack of appropriate source material on the air transport of irradiated reactor fuel elements, new reactor fuel, radioactive waste, and contaminated components to or from a remotely sited military nuclear power plant. One would have thought that, with the design, fabrication, and installation of the PM-1 military nuclear power plant at Sundance Air Force Station, Wyoming, sufficient precedents would have been established. Actually, though a great portion of the plant was airlifted, the question of airlifting the fissile or radioactive portions of the system was begged. As applications are continually being considered for siting nuclear power plants at remote locations which can be reached only by air, such as Byrd Station, Antarctica, it was felt that appropriate criteria must be delineated as soon as possible.

The Air Force Special Weapons Center (AFSWC), Nuclear Power Division, pointed out the need for a study of the airlift of such materials in a letter to Headquarters, Air Force Systems Command (AFSC) dated 29 October 1962. On 21 November 1962 the Deputy Inspector General for Safety, in a letter to AFSWC, reported that the requirement for Air Force Technical Order procedures dealing with the air transport of such materiel had also been identified by Hq Military Air Transport Service (MATs) and directed that AFSWC undertake the study. The designated project officer from the AFSWC Nuclear Power Division obtained Hq MATs concurrence on the proposed scope for the study on 19 March 1963. The effort was incorporated under Task 280004 of Project 2800 "Surface Nuclear Power Applications." The task title is "Surface Nuclear Power Safety Assurance." With the reorganization of certain AFSC elements under the Air Force Research and Technology Division, on 1 May 1963, the responsible project office became the Air Force Weapons Laboratory, Nuclear Power Branch (WLDN-1).

b. Scope

In establishing the scope of this study, it became evident that certain portions dealing with fissile and radioactive material would also be pertinent to the air transport of aerospace nuclear auxiliary power systems (here meant to be those power units designed for use in the atmospheric flight and space regimes). The scope of the study was then expanded to include the air transport of those items.

It is hoped that confusion does not arise from the fact that this report is designed to fulfill the needs of two types of readers. Since the primary purpose of the study is to demonstrate that the logistics of a remote power plant that can be reached only by air are practical, the primary interest will be in the System Project Office (SPO) for a military nuclear power plant intended for use at a remote site. For future Systems Project Offices, detailed packaging criteria have been delineated and desirable plant crew capabilities, operational procedures, and equipment design features have been highlighted. The packaging and transport plan, analysis, and approval chain have been specified for the SPO's use. In short, it is hoped that all of the source material the SPO requires and the restraints under which it must labor to develop an air-transportable nuclear power system (and this includes not only remote surface plants, but aerospace nuclear power systems as well) are contained within this report.

The other interested agencies are the Military Air Transport Service or the troop carrier organizations of the Tactical Air Command who would actually have to perform the airlift operation. It is hoped that much of the information developed for the SPO will serve as background information for Hq MATS and TAC safety personnel who are unacquainted with the various safety aspects of nuclear power technology and give them a better understanding of the prime safety considerations and the necessity for such operations. The sections of this report of prime interest to MATS and TAC will undoubtedly be those dealing with normal loading, normal flight, emergency and accident procedure standards, and special precautions which should be taken. Here, no attempt has been made to advise MATS or TAC on matters as familiar to them as the general considerations involved in the airlifting of heavy packages, but rather to discuss only those aspects of shipment which are peculiar to the

material being considered. Fortunately, these peculiar aspects are not extensive and most of them can be eliminated by proper planning on the part of the SPO.

It is hoped that each reader will bear in mind the fact that the report is prepared for Air Force-wide usage and will not regard certain portions as banal or others as superfluous, because of his particular background.

While this report has been prepared by an organization primarily concerned with future, advanced applications of nuclear power technology, within the Department of Defense, an attempt has been made to be as objective as possible. The fact that there are additional risks involved in air-transporting fissile and radioisotope materiel has not been whitewashed; rather an attempt has been made to point out that, while these risks may be greatly minimized by proper planning, a determination should still always be made as to whether the benefits to be derived from such operations are worth the risks involved.

## 2. BACKGROUND

### a. Support of remote and mobile military nuclear power plants

Nuclear technology has presently advanced to the point where it is capable of satisfying diversified Air Force power requirements. The inherent characteristics of reactor and isotope power systems (i. e., high power densities, less required logistic support, and lower operating costs in remote areas), make such systems highly attractive for use in both terrestrial, flight, and space applications.

Reactor powered, electric generating plants, now coming of age in the civilian power industry, are desirable for many military applications involving power requirements in the 1 to 2 megawatt electric range at remote sites. These are locations where the cost of establishing and operating an organically fueled generating plant are greater than those for the nuclear plant or where uncertain supply conditions might jeopardize the overall mission accomplishment of the installation. The development, testing and operation of the Air Force's PM-1 Nuclear Power Plant at Sundance AFS, Wyoming, the Navy's PM-3A plant at McMurdo Sound, Antarctica, and the

Army's SM-1A at Fort Greely, Alaska and PM-2A at Camp Century, Greenland all represent recognition by the Department of Defense of the advantages of nuclear power for such uses and of the need to develop such systems and capabilities.

While all of these plants are situated so as to be available by means other than air, many sites are presently being considered (as parts of advanced air defense systems or for geophysical expeditions) which can be supplied by air alone. The PM-1 and PM-3A plants were meant to be forerunners of such plants in that they were fabricated into modules capable of being airlifted to their destinations by C-130 aircraft. Indeed, all the major components of the PM-1, save only its reactor core, were actually airlifted from Baltimore, Maryland to Ellsworth AFB, South Dakota. Unfortunately, the failure to airlift the core (actually a small item compared to the modules which were flown) prevented this from being a demonstration of complete air portability. (In fact, no such air shipment has ever been made, save for the September 1962 shipment of PM-3A center bundles to Andrews AFB, Maryland from McMurdo Sound, Antarctica by way of New Zealand and return. These bundles were incapable of criticality and gave off no appreciable radiation and hence are not considered to be any major precedent.)

There is, however, a finite possibility that air shipments of nuclear power plants may be required in the near future. Should the PM-3B plant, which was recently considered for use at Byrd Station, Antarctica, be approved for installation, the entire plant would have to be airlifted a distance of at least 600 miles. Other remotely sited applications under consideration will not be discussed either because of classification or because of the preliminary nature of their requirements.

At the present time, there exists a dearth of satisfactory power generating devices in the low power range (10-150 Kwe) for mobile communications, weather, command and control, and aerospace ground equipment supporting mobile strike force and counter-insurgency concepts. Such forces, to date, have used diesel, gasoline, or gas turbine units to meet these requirements. These units have not been completely satisfactory for this use because of the high logistics requirements for fuel, considerable operations

and maintenance support requirements, and the poor reliability of the gas turbine units. It is within the state of the art to develop a direct conversion (thermoelectric) nuclear reactor power plant capable of meeting these requirements for mobile deployed mission support equipment. While significant reduction of logistics, maintenance and operations, and reliability problems would result, routine airlift capability for such systems would have to exist.

Similarly, the ML-1, a mobile gas-cooled reactor system (power level 340 kilowatts, electric) developed for the Army Corps of Engineers, is capable of being air lifted, from the standpoint of package weight and size, though such shipment has never been made. Again, this plant was developed as a forerunner of more advanced, higher power mobile plants. The follow-on concept, the Military Compact Reactor (MCR) appears to be in some straits at the present time; however, it is not unlikely that, as materials and other technologies are advanced as a result of work in space type reactor systems, the development of this type of reactor system will be resumed. Airlift capability would again be essential to the utility of such systems.

The core of a reactor power system is the energy source for the power conversion system and the source of all the radiation problems encountered in air transport of nuclear power devices. It is here that the fission process takes place. The energy released in fission neutrons, the fission fragment kinetic energy, and the energy absorbed by reactor materials or coolant from beta particles and electromagnetic radiation (see appendix I for definitions of the various types of radiation) are all transmitted, in part, to the core coolant for conversion either directly, or through an electromechanical conversion, to electric power. Approximately 84 percent of the heat energy is obtained from the kinetic energy of the fission fragments, 2½ percent from the fission neutron energy, 10 percent from the electromagnetic radiations, and 3½ percent from beta particles.<sup>1</sup> The radioactivity of the core elements is caused mostly by the decay of the fission fragments (eventually to a stable state), although some radiation emanates from the reactor structural materials activated by neutron bombardment.

A core representative of air transportable military nuclear power plants is that of the PM-1 (and PM-3A), (figure 1). The core is 23 inches in diameter and 33 inches high and is capable of producing 8.30 megawatts

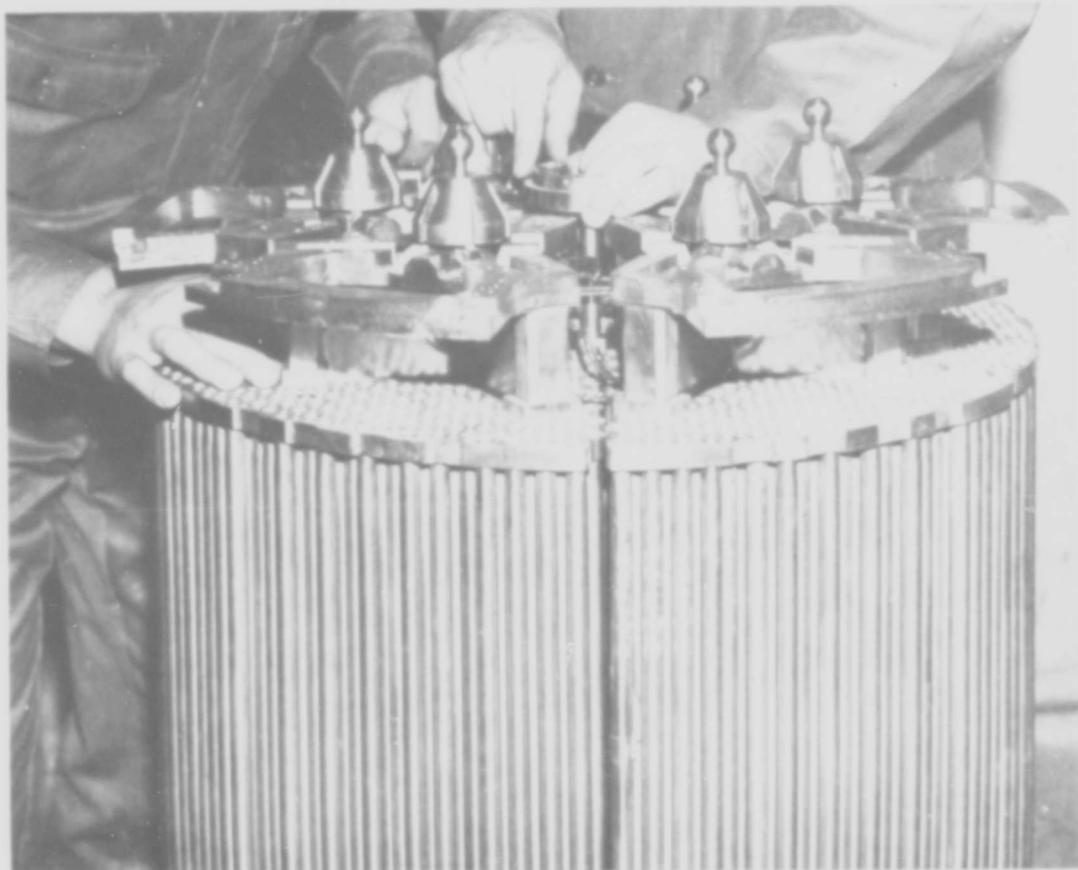
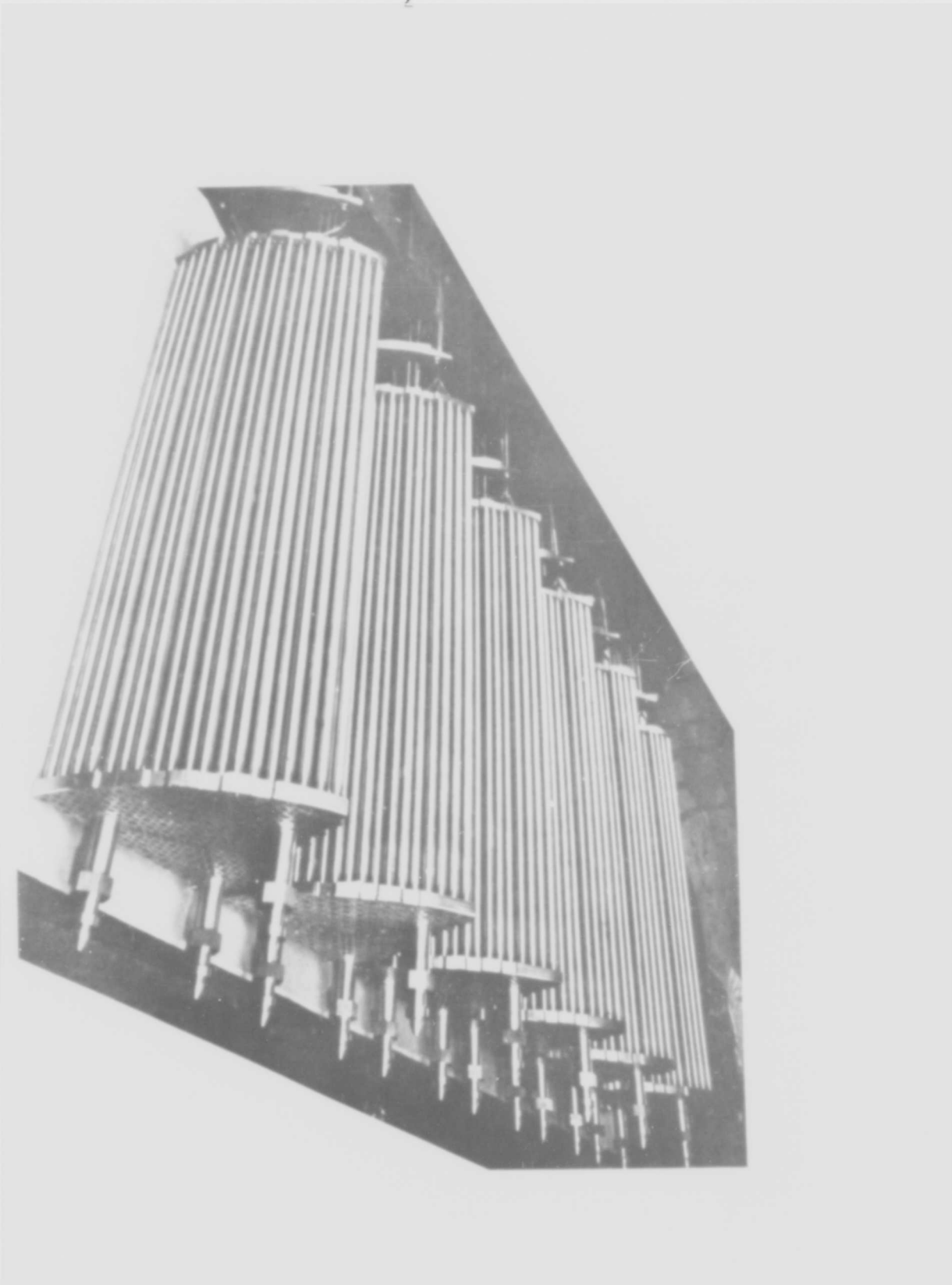


Figure 1. PM-1, PM-3A reactor core

(thermal) continuously for 2 years. It is composed of 741 fuel tubes containing the fissionable material, uranium, highly enriched in the isotope,  $U^{235}$ . At the current AEC credit value, a new core contains approximately \$410,000 worth of fissile material. Although the core is composed of six peripheral bundles (figure 2) and one small center bundle (not shown) it was designed to be shipped in an assembled configuration. Another core, that of the SM-1, SM-1A, PM-2A type\* is shown in figure 3. The SM-1 core is

\*The SM-1 is permanently emplaced at Fort Belvoir, Va., the SM-1A is permanently emplaced at Fort Greely, Alaska, and the PM-2A, a portable plant, is currently on-site at Camp Century, Greenland.

Figure 2. PM-1, PM-3A reactor core, peripheral bundles



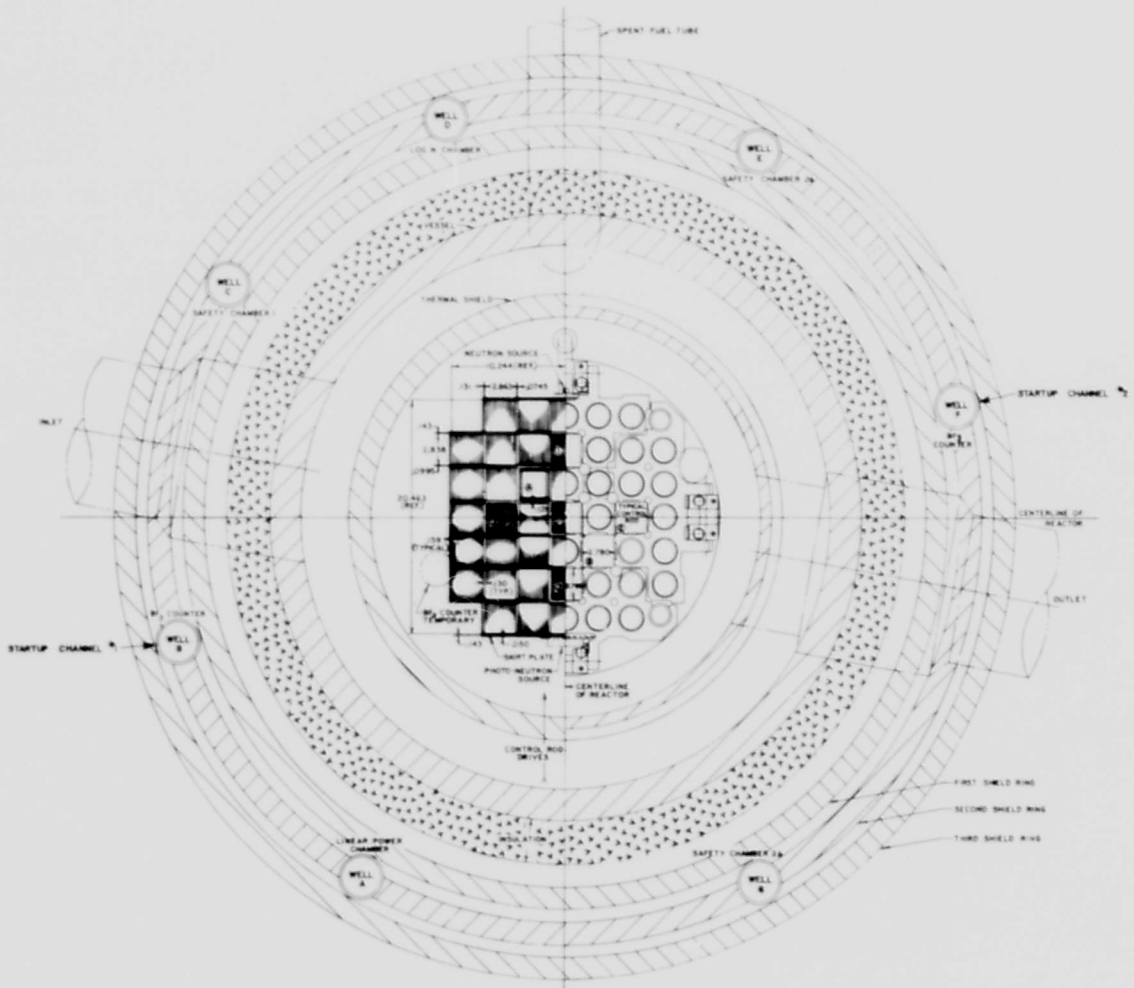


Figure 3. Plan view - SM-1 reactor core

roughly 20½ inches square and 34 inches long. It is composed of 38 fuel elements, each containing 16 fuel plates.<sup>2</sup> The SM-1 core is rated at 10.0 megawatts for 1 year of continuous operation.

The only completely portable prototype nuclear power plant developed to date is the ML-1, the reactor and power conversion skids of which are shown in figure 4. The core volume is a cylinder 22 inches in diameter and 22 inches long, containing 16 fuel elements. The core is capable of 3,000 hours operation at 3.3 megawatts thermal and is intended to be shipped within its reactor pressure vessel, shown in figure 4, which weighs approximately 15 tons.<sup>3</sup>

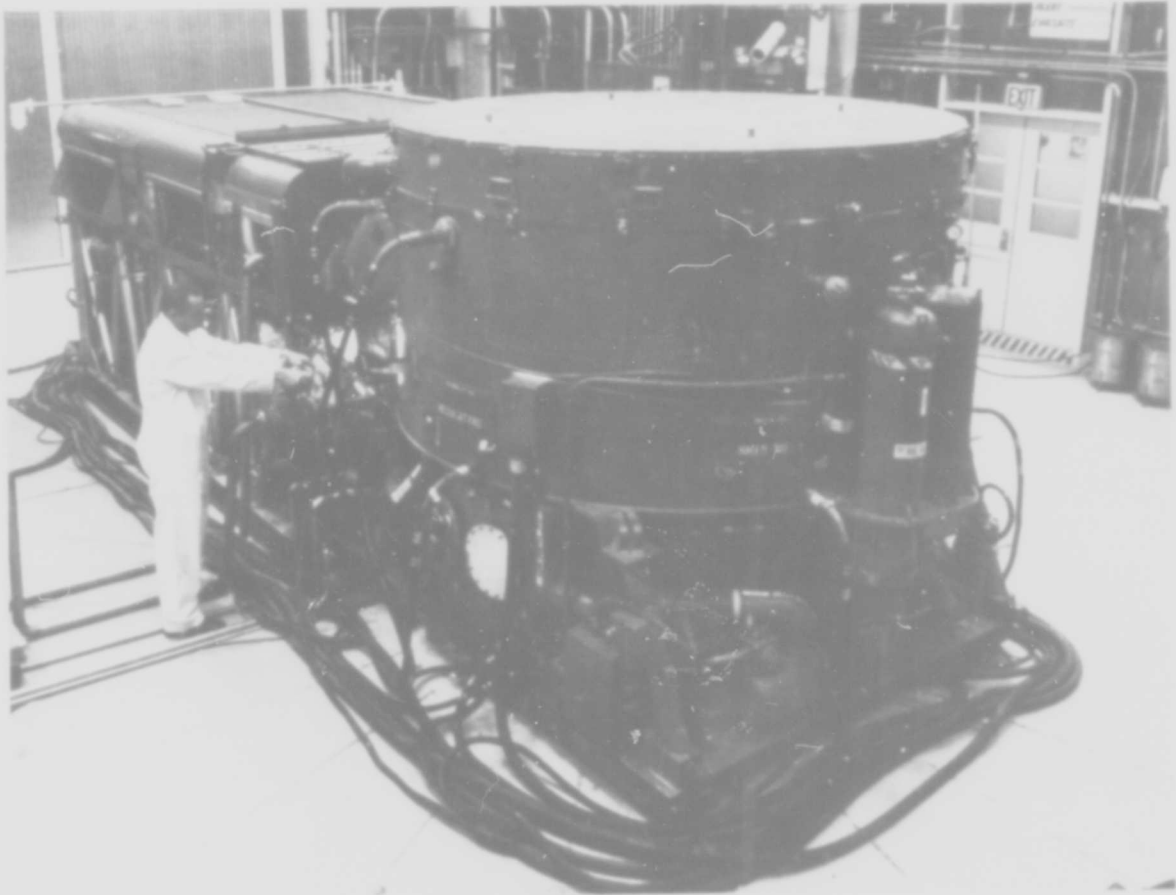


Figure 4. ML-1 reactor and power conversion modules

The PM-1, PM-3A, SM-1, SM-1A, and PM-2A nuclear plants mentioned above are pressurized water plants. That is, the core coolant is water under high pressure, whose energy is transferred to low-pressure water in a heat exchanger; the low pressure water evaporates to steam and expands through a turbine. Sometimes, a portion of the steam is extracted for heating base facilities. Those plants which have been termed "air transportable" are so to the extent that the major components are packaged in modules which can fit inside C-130 aircraft. Special site preparation is required for emplacement, and the disassembly of a plant is a very complicated, expensive, and time-consuming operation requiring extensive planning.

On the other hand, the ML-1 concept is completely transportable, in that no extensive site preparation is required and the plant can be re-located 24 hours after nuclear shutdown. The ML-1 reactor is gas-cooled and electric power is derived from a high-temperature gas turbine. The plant can be disassembled into three packages, each occupying one C-130, for airlift.<sup>4</sup> While present plans for airlift procedure have been deemed inadequate by the Air Force Special Weapons Center, this system could be safely airlifted, with proper tie-down design.

Reactor power systems such as these have associated with them four possible kinds of air shipments which require special precautions to ensure radiation health safety. These are listed below, starting with those materials which require the greatest precautions:

(1) Spent reactor fuel

As mentioned previously, atoms of the fuel material uranium are split by fission (releasing energy) into fission fragments which are atomically excited. These fission fragments, which decay primarily by the emission of beta particles (negative electrons) and gamma rays (electromagnetic radiation), have an estimated range in aluminum of 0.0014 m. Hence, unless the integrity of the fuel element cladding has been breached, the fission products will be contained as planned. Should a fuel element rupture have occurred, however, special precautions for this radiological contamination problem, which will not be discussed in detail in this report, must be taken.

The activity of fission fragments decays with time. Way and Wigner<sup>1</sup> give the following empirical relationship for the rate of emission of beta and gamma energy at time  $t$ :

$$\text{Rate of energy emission} = 5.9 \times 10^{-3} P \left[ (t - T_0)^{-0.2} - t^{-0.2} \right] \text{ watts}$$

where

$P$  = power level of the reactor in watts

$t - T_0$  = time after reactor shutdown, in days

$t$  = time after reactor startup, in days

The relationship is meant to apply out to  $(t - T_0)$  values of several weeks. After that time, the power (and hence activity) curve decreases at a lesser rate.

The magnitude of the radioactivity in a "spent fuel core" would probably preclude any disposal of it. In addition, economic considerations dictate that the fuel elements be reprocessed at either the Atomic Energy Commission's Idaho Chemical Processing Plant or its Savannah River Plant. At least 69 percent (and usually more) of the core's original charge of uranium will still remain to be recovered. (With the PM-1 core, this means it still contains at least \$284,000 worth of fissile material.) Also, some of the isotope fission products are long-lived enough to have considerable residual value, when separated from the mixture, for diversified applications such as in radioisotope generators for space use and in radio-biological research. Thus, spent fuel elements for military nuclear power plants will, for the foreseeable future, have to be shipped back to an AEC reprocessing plant.

Before this description of spent reactor fuel material is completed, it should be mentioned that such fuel elements are continuously emitting considerable amounts of heat. This is an important factor in the shipment of these materials, as will be seen later. The beta particles and gamma radiation energy entrapped in the fuel elements result in the element's becoming an effective heat source. The heat generation rate from this source is called the "fission product beta-gamma power." Figure 5 indicates the general shape of the curves which describe the decrease of fission product beta-gamma power, with time.

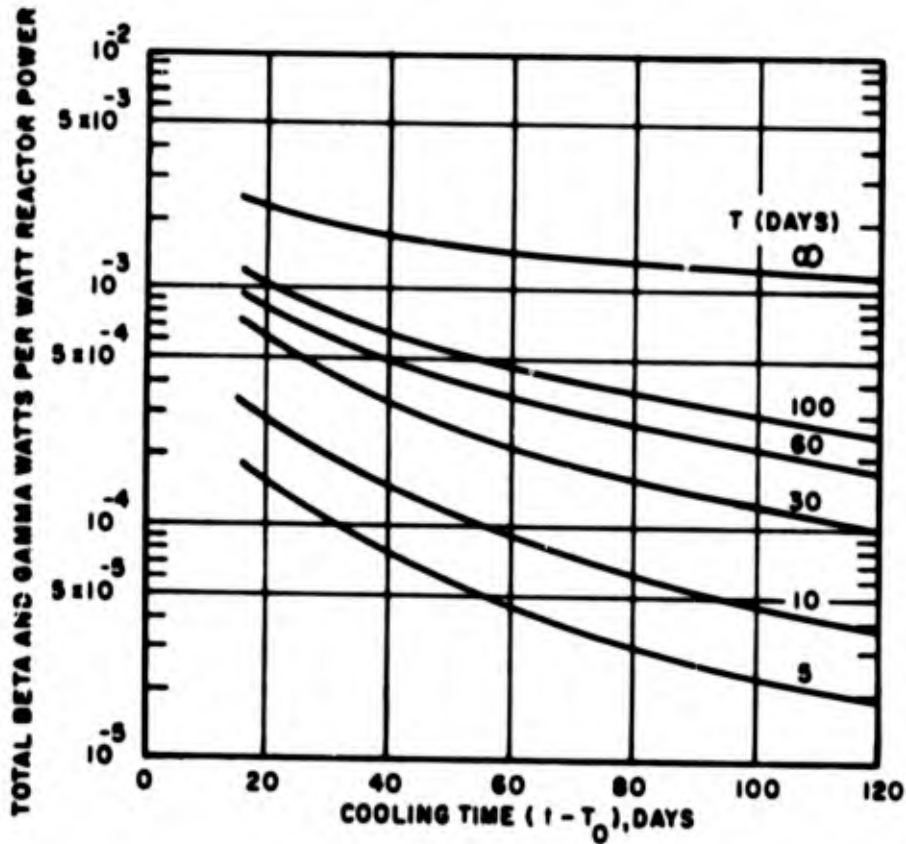


Figure 5. Plot of beta-gamma fission product power as a function of time

A final characteristic of the spent cores from military nuclear power plants that should be noted here is that while they may not be capable of maintaining the plant at full power, these cores, in their design configuration, are still capable of nuclear criticality, particularly with initial coolant temperatures lower than those specified for full power level operation of the core. Nuclear criticality is here meant to mean a sustained fission reaction.

Reactors in which fission is caused primarily by neutrons in the "thermal" (below 0.1 Mev) regime, which include the five military nuclear power plants previously mentioned, are more capable of criticality at lower coolant temperatures, where the hydrogen atom density in the coolant is greater. Collisions with hydrogen nuclei slow down "fast" neutrons to the thermal range, where they are used more efficiently for sustaining the fission chain reaction. Thus, the ability of these cores to achieve a nuclear criticality and hence an excursion (critical beyond control) must be considered in any plan to ship such items.

## (2) New reactor fuel

New reactor fuel is only slightly radioactive.  $U^{235}$  is generally taken to be stable, although in reality it does decay by medium energy alpha particle emission, with a half life of  $7.13 \times 10^8$  years. Likewise, the natural isotope of uranium,  $U^{238}$ , will always be present to a lesser or greater extent, depending upon the enrichment. It also decays by alpha particle emissions and has a half life of  $4.49 \times 10^9$  years.<sup>6</sup> These present no hazards to speak of, since their penetrations in air are only on the order of a few centimeters (2.7 - 3.1 cm) and they are stopped by the first epidermal layer of the skin. Shielding is not required in the transport of such materials. Also, because of this slight decay of the fuel material, there is no sensible heat generated within the core fuel elements. The only real, possible hazard in the shipment of new fuel is that of criticality when an assembled core is shipped. This is true whether the core is that of a military nuclear power plant or an aerospace reactor power system, as will be seen later.

Some of the pressurized water power plant cores have burnable poisons integral to their design. The effect of these poisons is to limit the initial reactivity of the core so that reactivity of the core at start-up is not significantly greater than that near the end of core life. (Reactivity may be crudely defined as an index of the ability of a given mass to achieve a level of nuclear criticality.) Hence, if we are speaking of shipping cores in toto, the criticality prevention problem is roughly the same whether the cores are new ("cold, clean") or spent (highly irradiated). It is the foremost problem in the shipment of new cores, however.

## (3) Radioactive wastes

The radioactive wastes encountered in the support of a military nuclear power plant are all generated within the nuclear core. Here we shall consider primarily stationary electric generating plants of the pressurized water variety, although the problems encountered with wastes from boiling water plants are generally the same. All five stationary plants presently in the military inventory are of the pressurized water variety, and in all probability any other plants constructed for the military in the next 5 to 10 years will be based upon the same technology. The sources of radioactive

waste in such plants are the following:

(a) Coolant water

Although great pains are taken to obtain high-purity make-up water, the reactor coolant water will inevitably contain some impurities. This will depend to some extent upon the plant location and local water conditions. These impurities, as they pass through the core, then become activated by neutron bombardment. Also, the water itself, or more properly the hydrogen and oxygen of the water, produce radioactive isotopes upon neutron bombardment.

(b) Structural materials

The core itself is a major source of contamination. The primary construction material, usually stainless steel, though possibly aluminum or even carbon steel, will contain iron and alloying agents such as manganese, nickel, cobalt, and carbon in carbon and stainless steel; while nickel, iron, titanium, silicon, copper, cobalt, and cadmium may be found in aluminum alloys. Some of these activated elements are removed by corrosion or erosion from the surface of core structural elements and fuel elements and enter the reactor coolant stream, from which they must be removed. Conversely, corrosion products from the primary system, upon passing through the core, become activated by the high neutron flux. Other atoms of fuel cladding that are not on the immediate outer surface may be knocked out of their positions in the lattice of metal atoms by neutron collisions. Some of these "recoil" atoms are close enough to the fuel element surface to escape from the cladding into the coolant stream, becoming another source of radioactive contamination.

(c) Fission products

A primary consideration in the design of fuel elements is the containment of fission products. In spite of this, however, fuel elements have been known to fail, releasing fission products into the primary system. Depending upon the magnitude of the cladding failure, this can be a source of considerable radioactive waste.

(d) Gaseous radioactive wastes

Some of the fission products generated in the fuel element meat are gaseous at normal and operating temperatures and may diffuse through the fuel element cladding to enter the reactor coolant stream. These gases will accumulate at the high point of the system and will have to be periodically vented. These gases are monitored, and if found to be above acceptable concentration limits, are processed. The common way of doing this is to discharge them through a silver nitrate chemical reactor in which the iodine-131 (the most hazardous isotope) will react to form silver iodide. Other chemicals may be used for this purpose. Periodically, the charge of the chemical reactor, which has become contaminated and chemically depleted, must be replaced. The old charge, which may be inseparable from the reactor hardware, will have to be removed to a disposal site in most cases. The direct radiation emanating from this chemical charge will be of a low level, however; otherwise plant personnel would not be able to perform the recharging operation on site. If radiation levels are unacceptable, one need not wait long for them to diminish appreciably, as  $I^{131}$  has a half-life of 8.05 days. The primary hazard associated with gaseous fission products is not the direct radiation streaming from a concentration of them, but rather the internal dose received by man should he ingest them via inhalation. Safely contained or entrapped, they are relatively innocuous.

(e) Other sources of wastes

In addition to the sources of waste just discussed, one may expect to find that all of the water from nuclear plant washing machines in which contaminated clothing is washed, and all laboratory, sink, and floor drains into which contaminated water may be dumped, will drain to a central collection tank for the waste concentration system.

(f) Concentration of wastes

In pressurized water power plants and boiling water plants also, the liquid and solid radioactive wastes which originally came from the coolant water, primary system structural materials, and escaped fission products will usually be concentrated in ion exchange demineralizer beds. A usual procedure in a pressurized water plant, for instance, is to continuously

divert a small portion of the primary system coolant (called primary blow-down) through a demineralizer where the contaminants will be trapped by the bed's filtering action and fixed by the resin's ion exchange process. In the past, small metallic "cuno" filters were used to trap solid wastes; now the trend is to remove these filters from the system and to depend upon the resin bed to act as a filter also. In most plants there is usually sufficient storage and processing capacity to hold and process the entire amount of the primary system coolant in the event of a serious fuel element failure.

One can then see that the draining of all of the contaminated and possibly contaminated water would result in a considerable volume of low-level activity water being collected in a relatively short time. If these wastes must be transported some distance from the plant, as is assumed here, economic considerations dictate that these wastes should be concentrated in some manner.

The usual manner of concentrating wastes is by the evaporation of the bulk of the water. Remote military nuclear power plants built to date, which are not allowed to dispose of low level wastes on site, are equipped with such evaporators. These evaporator systems are capable of volume reductions of 60 to 1. The remaining residue is a sludge of specific gravity in the neighborhood of 1.3. Common practice is now for spent demineralizer ion-exchange resins, usually utilized to purify and filter the primary system blowdown, to be flushed directly to the still pot or evaporator and become mixed in with the above mentioned sludge.

Another possible method of concentrating liquid radioactive waste is by means of coagulation or chemical precipitation. While this mechanism is used at fuel element reprocessing facilities on high level waste, to recover certain radioisotopes such as those of strontium and plutonium, only in a few isolated instances is chemical precipitation used in low level waste treatment because (1) such techniques are of more value in the treatment of large volume wastes, and (2) because of the widely varying characteristics of the chemical species present, most such scavenging procedures are relatively inefficient for gross removal of fission products.

Adsorption on clay has been proposed as a means to concentrate fission and activation products at remote sites. This is essentially an

ion exchange phenomenon and has not been used by any military nuclear power plant to date.

One may see that the previously discussed concentration operation (almost always, for the purposes of this study, taken as being an evaporation operation) is conducted on-site, as a batch process, when the liquid waste reaches a certain level in the storage tanks.

At the present time no use is made of these wastes because of the economics involved in processing them for particular isotopes. At the same time, however, it is usually not possible to make ultimate disposal of them at the plant site where they are generated. Local health considerations or legal restraints (such as the Antarctic Treaty or the agreement with the Danish government on the use of Camp Century, Greenland) usually require that the wastes be transported to a National Disposal Site.

Since the isotopes themselves are worthless, they may be put in storage for a considerable period of time to allow the activity to decay down to lower levels, before shipping. The only time when this might not be allowable is when the entire plant is to be relocated and sufficient time is not available for the more recently generated waste to decay down to more desirable levels.

(g) Hazards of radioactive waste

The only hazard associated with radioactive waste in sludge form is the possibility of contamination and ingestion upon leakage. As such, it is highly desirable that this sludge be converted into a physically stable form so that there is no possibility of contamination through contact with the leakage.

(4) Contaminated tools and components

Occasionally, in the support of a military nuclear power plant, it becomes necessary to transport plant components or tools which have become contaminated. This contamination may be either surface contamination resulting from contact with coolant containing radioisotopes or it may actually be a result of activation within the item itself due to neutron bombardment. In either case, unless the item has been subjected to in-pile radiation, the

level of radioactive contamination should be quite low. The hazard which should be anticipated here is the possibility that radiological contamination might be ingested into the body via the hand-to-mouth route from the tool or component. Direct radiation from these articles will usually be negligible.

In the case of components of military nuclear power plants, the appreciable capital cost of the items may dictate returning them in the inoperative state, for repairs which cannot be made at the plant site. In pressurized water power plants, components of the primary system such as valves and primary canned rotor pumps (which may cost as high as \$135,000 each) are examples of items which, though contaminated, are certainly worth the extra precautions required to bring them back into an operative condition. Special tools, jigs, and transport containers are themselves items which, when used in support of more than one plant, may require periodic airlift from site to site to obtain the cost savings accrued from avoiding equipment duplication.

Obviously, this class of items must be shipped by air from those plants which are located at sites which can be supported only by air, when the time comes to remove the plant. A good example of this would be encountered with the PM-3B, should it ever be built. The Antarctic Treaty forbids contaminating the continent by leaving radioactive material behind, when the time comes to close down the plant. Many parts of the plant would come under the category of contaminated tools and components, including the entire primary system (without core).

Whenever such shipments are to be made, the plant crew will first of all make every effort to decontaminate the item or items as completely as possible. Many different methods of surface decontamination are used. Usually, commercial detergents are tried first. Decontamination procedures suggested in reference 5 (excerpted and paraphrased) are given in table 1.

The decontamination factors achieved by these treatments sometimes run as high as 70 but sometimes are ineffective, depending upon such variables as the surface conditions, type of contamination, etc.

Table 1

DECONTAMINATION PROCEDURES (listed in order of preference)

Contaminated Material	Decontaminating Agent	Remarks	Maximum suggested levels of contamination
Classware	Soap or detergent and water	Monitor wash water and plan disposal of it	150 d/m/100 cm <sup>2</sup> of alpha, 0.3 mr/hr/100 cm <sup>2</sup> for beta and gamma
	Chromic acid cleaning solution or concentrated nitric acid	Monitor wash water and plan disposal of it	150 d/m/100 cm <sup>2</sup> of alpha, 0.3 mr/hr/100 cm <sup>2</sup> for beta and gamma
	Oxalic acid 5 percent (caution - poison)	ELEMENTS REMOVED Zr, Ng, Hf	150 d/m/100 cm <sup>2</sup> of alpha, 0.3 mr/hr/100 cm <sup>2</sup> for beta and gamma
	Versene (EDTA) 5 per cent conc. NH <sub>4</sub> OH 3 per cent HCL 10% by volume. (To make, dissolve in order (1) versene (EDTA) 5 percent (2) Conc. NH <sub>4</sub> OH, 3. per cent by volume (3) glacial acetic acid 5 per cent by volume)	Alkaline Earth Metals: Be, Mg, Ca, Sr, Ba, Ra, P as PO <sub>4</sub> . Alkali Metals: Nd, Kr, Rb, Cs and strongly absorbed metals like Po. Trivalent Metals: Al, Sc, Y, La, Ce, Pr, Nd, Pm, Sa, Eu Rare Earths: Ac, Ga, In, Tl, B Transition Metals: Cu, Zn, Fe, Co, Ni, Cd, Sn, Hg, Pb, Th, U, Ag (Always consider the radioactivity of the cleaning solution when disposing of it.)	150 d/m/100 cm <sup>2</sup> of alpha, 0.3 mr/hr/100 cm <sup>2</sup> for beta and gamma
Metal Tools	Detergent, Dilute nitric acid, 10 per cent of sodium citrate or ammonium bifluoride	As a last resort use HCL on stainless steel	150 d/m/100 cm <sup>2</sup> of alpha, 0.3 mr/hr/100 cm <sup>2</sup> for beta and gamma
	Metal polish, sandblasting and other abrasives	Such as brass polish on brass (Use caution as these procedures may spread contamination)	

Table 1, Contd.

Contaminated Material	Decontaminating Agent	Remarks	Maximum suggested levels of contamination
Plastic Tools	Detergent Ammonium citrates, dilute acids, organic solvents		150 d/m/100 cm <sup>2</sup> of alpha, 0.3 mr/hr/100 cm <sup>2</sup> for beta and gamma
Rubber	Washing or dilute HNO <sub>3</sub>	(Short lived contamination may be covered to await decay).	150 d/m/100 cm <sup>2</sup> of alpha, 0.3 mr/hr/100 cm <sup>2</sup> for beta and gamma
Leather		Almost impossible to decontaminate	150 d/m/100 cm <sup>2</sup> of alpha, 0.3 mr/hr/100 cm <sup>2</sup> for beta and gamma
Linoleum	CCl <sub>4</sub> , kerosene, ammonium citrate, dilute mineral acids		150 d/m/100 cm <sup>2</sup> of alpha, 0.3 mr/hr/100 cm <sup>2</sup> for beta and gamma
Ceramic surfaces	Detergent Mineral acids, ammonium citrate, trisodium phosphate	Scrub hot 10 per cent solution into surface and flush thoroughly with hot water	150 d/m/100 cm <sup>2</sup> of alpha, 0.3 mr/hr/100 cm <sup>2</sup> for beta and gamma
Painted Surfaces	Detergent CCl <sub>4</sub> , 10 per cent HCl acid	Usually best to remove paint and repaint	150 d/m/100 cm <sup>2</sup> of alpha, 0.3 mr/hr/100 cm <sup>2</sup> for beta and gamma
Brick and concrete	32 per cent HCl acid	If this is not successful, concrete must be removed.	150 d/m/100 cm <sup>2</sup> of alpha, 0.3 mr/hr/100 cm <sup>2</sup> for beta and gamma
Wood	Detergent Hot citric acid, remove surface with plane, floor chipper or grinder		150 d/m/100 cm <sup>2</sup> of alpha, 0.3 mr/hr/100 cm <sup>2</sup> for beta and gamma

The example of the controls placed on such articles at the Duquesne Power & Light Company's shippingport reactor plant may be instructional, here. The limits of radioactivity and contamination for repair work which have been established for the Shippingport plant are as follows:

(a) For release to a repair shop with health physics monitoring facilities, the surface contamination must be less than 500 disintegrations/min, ft<sup>2</sup>. The radiation level at the surface must be below 0.1 mr/hr.

(b) For release to normal repair shop facilities out of plant, the surface contamination must be less than 100 disintegrations/minute, ft<sup>2</sup>, and radiation level at the surface must be below 0.1 mr/hr.

These values are very low for transport where the items may be packaged, but are indicative of the levels of contamination which nuclear plant supervision will be willing to release.

b. Aerospace power systems

Nuclear power technology is also making a place for itself in this country's military and civilian space programs. In this regime of operation, the characteristics of high power-to-weight ratios — long life times, high reliabilities, and the lack of requirements for a precise orientation towards the sun — all have obvious advantages. We shall concern ourselves here only with auxiliary power sources which would be used for space life support systems, for instrument and radio transmitter power, or as electric power supplies for low-thrust, electrical propulsion space engines. This is as opposed to nuclear propulsion devices which use a reactor as a direct cycle heat exchanger to expand the propellant, such as the Nerva-type nuclear rocket engine or the Pluto-type nuclear ramjet engine. These nuclear systems will not be considered as prime candidates for airlift. Standards developed for other reactor devices will apply to these, however, though the magnitudes of the excursions which these reactors are capable of are considerably greater than those for the auxiliary power units to be considered here.

(1) Power reactor systems

While the exact lower limits are difficult to define, one may safely say that any space power requirement calling for power in excess of 400 watts(e) for periods longer than 100 hours can only be satisfied by reactor

power supplies. These systems are designated as the even-numbered SNAPs (Systems for Nuclear Auxiliary Power) and the first available unit which is the SNAP 10A. A SNAP 10A reactor mock-up is shown in figure 6. Booster considerations dictate a small reactor. Neutrons in the epithermal region ( $10^5$  ev) are used for fissioning as opposed to the thermal neutrons used in larger reactors, even though this dictates a more inefficient utilization of the fuel, as a smaller reactor results. The only heat dissipative mechanism available in space is radiation. With SNAP reactor power units one usually finds high-temperature heat-transfer fluids (usually liquid metals) and refractory materials. Also, the energy conversion equipment will be integrated into the mechanical design of the system to a greater extent than will be found with terrestrial units, for the sake of compactness. An additional primary hazard then stems from the fact that liquid metals (in the SNAP 10A a mixture of sodium and potassium) will be found within the reactor package. Fortunately, the inherent compactness of the units lends itself to high integrity packaging, even though environmental control equipment must sometimes accompany the package. As only new units will be shipped (obviously no used units will be available) the prime considerations are then the prevention of criticality and the retention of the liquid metal.

Here the shipment of the power unit to a remote spot on the earth's surface (which cannot be reached by other types of transportation) will not be a requirement. Air shipment, probably from a contractor's plant or test facility to the launch site, would be dictated by a desire to simplify the shipment plan, especially when several coast-to-coast trips for item testing, payload integration, etc., and delivery to the missile range are involved.

## (2) Radioisotope generator systems

Radioisotope generator units have been proposed and already used for space terrestrial and undersea systems which have electrical power requirements on the order of watts (or a few hundred watts) and require this power for extended periods of time. An unclassified listing of some of the radioisotope generators developed, or in development, is given in table 2. Generally, a portion of the heat liberated when radiation, emitted from the radioisotope fuel in its unalterable decay scheme, is converted to electricity

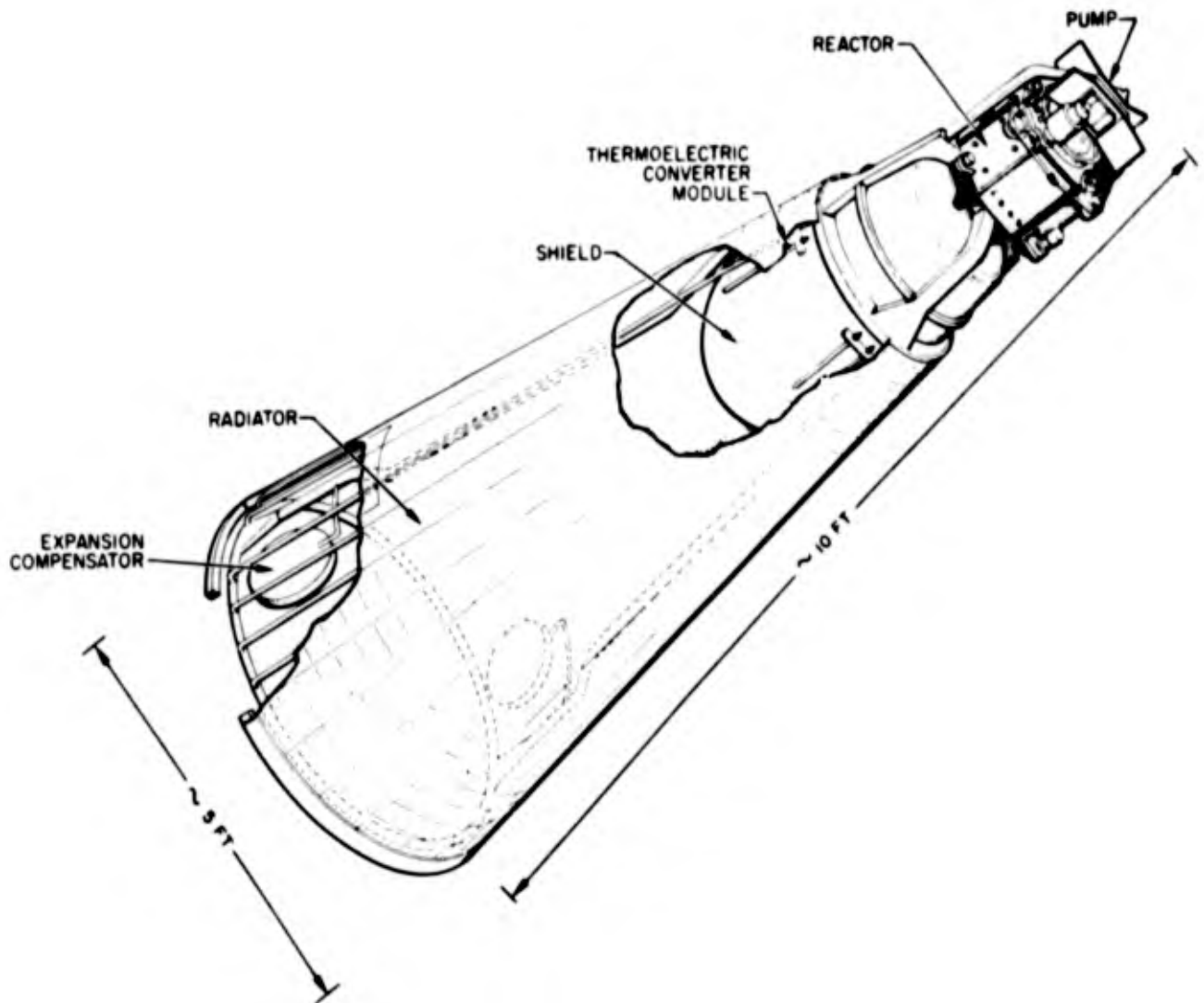


Figure 6. SNAP-10A system

by means of thermoelectric or thermionic converters. The advantages of such auxiliary power units lie in their inherent dependability, compactness, simplicity, and the lack of any requirement for any specific orientation in space (such as with solar cells). Cost and sometimes special handling considerations constitute disadvantages to be considered in the utilization of such units.

Radioisotopes are produced either as a result of the fission process (discussed previously) or as a result of neutron bombardment within a reactor. The Atomic Energy Commission is presently promoting the use

Table 2  
SNAP ISOTOPIC POWER GENERATORS

SNAP no.	Power (watts)	Use	Fuel	Unit design life	Status
3	2.7	TRANSIT 4A & 4B	95 gm Pu-238	5 yr	In orbit
	5	Weather (WB)	18 kc Sr-90	2 yr	Operable
7A	10	Navigation (CG)	41 kc Sr-90	10 yr	Operable
7B	60	Navigation (CG)	225 kc Sr-90	10 yr	Operable
7C	10	Weather (Navy)	41 kc Sr-90	10 yr	Operable
7D	60	Weather (Navy)	225 kc Sr-90	10 yr	Operable
7E	6.5	Sonar (Navy)	31 kc Sr-90	10 yr	Deliv. 5/64
7F	60	Navigation	240 kc Sr-90	10 yr	Deliv. 9/64
9A	25	DOD satellites	* Pu-238	5 yr	In orbit
11	25	Moon probe (NASA)	* Cm-242	90 day	Deliv. 1966
13	12.5	Thermionic (AEC)	* Cm-242	90 day	Under Dev.
15A	0.001	Nuclear weapons	2-3 gm Pu-238	5 yr	Under Dev.
15B	0.001	Nuclear weapons	2-3 gm Pu-238	5 yr	Under Dev.
17	30	Comsat (DOD)	* Sr-90	3-5 yr	Under Dev.
19	20	IMP (NASA)	* Pu-238	5 yr	Under Dev.
21	10	Adv. undersea	* Sr-90	5 yr	Under Dev.

\*Fuel quantities classified.

of fission products for such applications, whereas previously these were considered to be only wastes. As one may see from figure 7, plutonium 238, strontium 90, and curium 242 are presently the most commonly used isotopes.

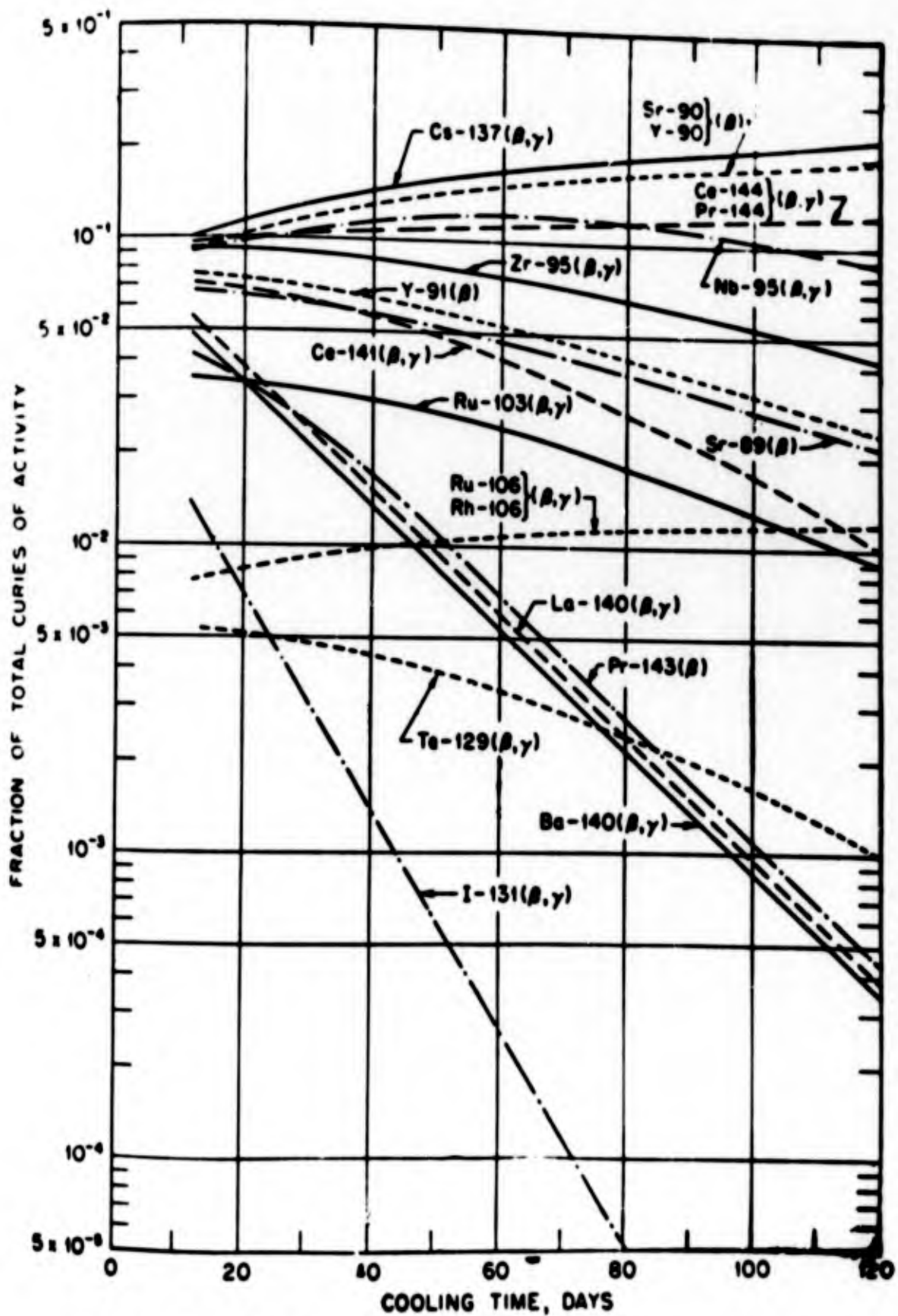


Figure 7. Relative activity of major fission products

All radioisotopes undergo decay eventually to a stable state. For example: plutonium 238 decays to uranium 234 by the emission of an alpha particle with a gamma photon occurring 24 percent of the time. It has a half life (the time it takes for half of the atoms present at one time to disintegrate) of 89.6 years. Curium 242 decays by the emission of alpha particles with a half life of 162 days. Weak gammas are also emitted. Strontium 90 decays to yttrium 90 by beta emission with a half life of 19.9 years. Many of the "daughter products" of these radioisotopes are not in a stable state and are themselves radioisotopes which have many transitions to make before they reach a stable state. Complete decay schemes may be found in reference 6.

All of the radioisotope generator units designed to date have utilized thermoelectric converters and are designated as RTG's (radioisotope-thermoelectric generators). The conversion efficiency of such devices is usually on the order of 5 percent. These thermoelectric converters consist of junctions of dissimilar materials whose work functions (a measure of the strength with which an electron is bound to the surface of the material) are such as to induce an electron flow (or a current flow) upon the proper application of a temperature gradient. In general, the "hot side" of the thermoelectric junction faces upon a radioisotope fuel capsule and the "cold" or heat rejection junction is in intimate contact with the outer skin of the RTG which is designed to dissipate the rejected heat by radiation in space or by conduction or convection (for terrestrial applications). Hot side temperatures of 1,000°F and cold side temperatures of 300°F are fairly typical.

Thermionic converters have been proposed for use as conversion devices in radioisotope generators; one such generator is presently being designed, the SNAP 13. Thermionic conversion, in which a hot electrode actually liberates excited electrons which are then induced to migrate to another colder electrode, resulting in a current flow, requires much higher temperatures (up to approximately 2,700°F) than does thermoelectric conversion and thus generates considerable materials problems. For this reason, the majority of the present work in the field of thermionics may be properly classified as research, whereas RTG units have been designed and put into use to satisfy the power requirements of DOD satellites, remote

meteorological station transmitters, and ship channel buoys. Thermionic conversion, when developed to an operational state, will convert thermal energy into electricity at a much higher efficiency than thermoelectric conversion.

As one may see, radioisotope generators deliver their full heat energy continuously, altered only by the gradual decay of the fuel material. This is quite different from an aerospace reactor unit which delivers heat only upon the programmed startup of the reactor. The full heat energy of the radioisotope generator must be continually dissipated during transport. On the other hand, comparing radioisotope generators and reactor systems, there is obviously no criticality hazard with the former since they are not constructed of fissionable material. Regarding radioisotope generator heat dissipation, the contractor is usually charged with proving that even if the unit is buried in soft earth as a result of a transport or launch mishap, the heat dissipation mechanism will be adequate to prevent the meltdown of the fuel capsule and the subsequent release of isotope material.

In the case of all isotope generator units designed to date, the external radiation levels have had to be low enough to permit considerable handling by ground crews at the missile site or when installation is made in a terrestrial unit. The maximum permissible radiation dose rates, established by the National Committee on Radiation Protection for occupational personnel, have been assumed to apply to personnel working around isotopic sources and preparing them for launch. The recommended maximum allowable doses, integrated over a 13-week period, without reference to instantaneous dose rate, have been taken to be 3 rad of gamma and 0.3 rad of fast neutrons for whole-body exposure and 25 rad of gamma and 2.5 rad of neutrons for exposure of hands and arms. To date, radioisotope units have not required additional shielding to meet such requirements although some such units have been shipped in "birdcages" to make use of the distance factor in controlling exposure levels. Future RTG systems, particularly those of significantly higher Sr<sup>90</sup> loading such as the SNAP 17, being designed for the DOD Medium Altitude Communications Satellite System, may well require auxiliary shielding to protect ground handling personnel.

Requirements for the airlift of such radioisotope generators would stem from the need to deliver them to remote locations, from security considerations or simply from a desire to expedite shipment.

### 3. NUCLEAR SAFETY ANALYSIS AND APPROVAL CHAIN

In keeping with the current Air Force weapon system concept, it is to be expected that the logistics involved in supporting a nuclear power system will be regarded as an integral and inseparable part of the system and that the investigation and certification of the safeguards of the logistic equipment and operations will be included as part of the investigation and certification of the entire system's safeguards. The Air Force ensures that maximum safety is designed into nuclear power system equipment and operations by the use of the safety studies, rules, reviews, and surveys delineated in Air Force Regulation (AFR) 122-15, "Nuclear Reactor System Safety Studies and Safety Rules." This regulation will undoubtedly be used by the Air Force to ensure the adequacy of the safeguards built into any scheme for the air logistic support of any nuclear reactor system (defined in AFR 122-15 as "any nuclear system which uses a radioisotope as a source of auxiliary power").

Other segments of the government and agents of government organizations also have established standards with which compliance must be proved, in certain instances. This applies not only to the obvious cases, in which the Defense Department utilizes regular civilian road, rail, or water transport facilities for the sake of expediency, but even in certain cases where the military will have control of the material from the point of origin to the destination.

#### a. Remote terrestrial nuclear power plants

It is essential to the operational utilization of an Air Force terrestrial nuclear power plant that it be supplied with new reactor fuel and that irradiated reactor fuel, radioactive wastes, and contaminated tools and components can be shipped from it, as needed. Since the safety of these operations can be properly classified as nuclear or radiation safety, these functions will fall within the purview of AFR 122-15.

The requirements for air logistic support might be first identified, formally, in the Site Evaluation Safety Study. Special measures required to render nuclear operations at that site safe are generally identified at that time. The implications, bearing upon the system development program and design, of such considerations as the facts that the site can be supplied only by air, or that no disposal of radioactive materials is allowed on site, etc., are pointed out in this stage of the Air Force nuclear safety approval chain.

For the first plant to be logistically supported by air, the problem of obtaining certification for packaging design criteria and operating procedure standards arises. While the reason for pursuing this objective at this stage may not be readily apparent, the packaging design must be accomplished prior to the next round of safety reviews; hence the need of approval of some criteria is immediate, and the requirement for special precautions in packaging and air operations does stem from the remote location of the site.

It is hoped that the criteria proposed in this report will serve as at least a base for these specifications. While every effort has been made to ensure that minimum ICC and AEC standards for surface transport are met, a thorough check of such pertinent standards should be made to ensure that any updating or revisions made by those agencies is not overlooked. For irradiated fuel, coordination should be established with the AEC Operations Office which administers the plant which will reprocess the spent fuel. Coordination should also be established with the Air Force Special Weapons Center, Test Directorate, Test Division, Laboratory Branch (SWTTL) regarding aircraft tie-down and parachute criteria and with the Air Force Weapons Laboratory, Development Division, Weapons Integration Branch, Technical Manuals Section (WLDW-5) regarding aircraft loading and unloading. These organizations will not only pass upon the adequacy of packaging plans and criteria but may be called upon to render consultation and advice during the system's design phase. The Bureau for the Safe Transportation of Explosives and other Dangerous Articles (hereafter called the Bureau of Explosives) of the Association of American Railroads, 63 Vesey Street, New York 7, New York, should be contacted at this point.

The Bureau of Explosives acts as the Interstate Commerce Commission's enforcement agency for civilian terrestrial transport and, in addition, passes upon the design of all irradiated fuel element casks, as required by the AEC for its reprocessing plants, before these plants will accept the shipments. The Bureau of Explosives will likewise provide consultation, as appropriate and if needed, during the equipment design phase of the nuclear power plant system.

Assistance in analyzing a design can be obtained from the AEC Division of Reactor Licensing (DRL), Bethesda, Maryland, if desired. In particular, assistance in evaluating the design for compliance with the nucleonics and mechanical integrity criteria can be obtained from DRL.

Each of the three safety studies which must be performed upon the system must be submitted and reviewed by the USAF Nuclear Reactor System Safety Group (NRSSG) which is convened and chaired by the Directorate of Nuclear Safety (DNS) acting as a field extension of the Deputy, The Inspector General for Safety (D/TIG) at Kirtland AFB, New Mexico. The membership of the NRSSG includes one member from each of the following: DNS, which provides the chairman, each Air Staff office (including the Surgeon General) or major air command with safety responsibilities (as determined by D/TIG) for any portion of the nuclear reactor system/facility, the Atomic Energy Commission if it so desires, and other government agencies (as determined by D/TIG). Each technical or logistic support agency (the System Project Office, the Air Force Ballistic Systems Division, etc.), having some responsibility regarding the system will be invited to designate non-voting members to the NRSSG, who will have an advisory status. Advisors may express their views through their respective command members of the NRSSG. The collection and assimilation of the technical input data and the preparation of technical nuclear safety analysis and evaluation studies for review by the NRSSG are the responsibility of the Air Force Systems Command (AFSC). Within the Air Force Systems Command, the Air Force Weapons Laboratory, Analysis Division, Safety Branch, Nuclear Reactor Section (WLAS-1) at Kirtland AFB, New Mexico, normally fulfills this responsibility. Equipment design and planned operations of plants procured through the Atomic Energy Commission's channels may also be submitted

for review, to the AEC Advisory Committee on Reactor Safeguards (ACRS) by way of the AEC Division of Reactor Licensing. The ACRS reviews, however, are not established to coincide with system development program milestones, as are the Air Force reviews under AFR 122-15; it is the responsibility of the AEC/DOD development agency to make submissions at the appropriate times, through the Division of Reactor Licensing. The decision as to whether or not ACRS reviews must be made in addition to Air Force reviews under AFR 122-15 must be based upon guidance received from the Deputy, The Inspector General which in turn will depend upon the particulars of the system development program and especially the channels through which the system is procured.

At such time as the major items of the system design have been determined, the NRSSG will make its second review, the Initial Safety Study. This is to identify safety deficiencies in design studies and provide guidance for whatever further development is required to enable the system to meet established safety standards. At this time, the logistic support cycle, and in particular the details of the irradiated fuel element, new fuel element, and radioactive waste packaging design, and the exact complexion of the projected air transport operations should be investigated.

Prior to this review, the Air Force Sponsoring Agency should have written analysis of all proposed aircraft tie-down configurations from the Air Force Special Weapons Center (SWTTL), the proposed loading and unloading operations from the Air Force Weapons Laboratory (WLDW-5), and an analysis from the appropriate AEC Operations office and the Bureau of Explosives of proposed irradiated fuel element casks. Proposed flight operations profiles should have previously been coordinated with the airlift agency (MATS or TAC) and guidance for foreign overflight procedures should have been obtained as per section 6a of this report. Packaging designs such as those for radioactive waste and unirradiated reactor fuel, which may not require AEC or Bureau of Explosives approvals, should have been analyzed to the satisfaction of the Air Force Weapons Laboratory (WLAS-1) at this time, unless some other agency is preparing the Initial Safety Study for the NRSSG, which is not expected. In that case, however, the analyses must be made to the satisfaction of the other government agency.

At the conclusion of the NRSSG Meeting for the Nuclear Power System Initial Safety Study and with the signing off by Hq USAF on the recommendations in the report, packaging design and proposed methods of tie-down, aircraft loading, and unloading will stand approved.

No later than 90 days before the time at which any of the operations considered in the two previously mentioned safety studies are to commence, the report of the NRSSG meeting held to review the Pre-Operational Safety Study should be submitted to Hq USAF.

The avowed purpose of the Pre-Operational Safety Study is to determine the adequacy of the safety features in the nuclear power system design, construction, and proposed operational procedures and to provide a basis for developing detailed safety rules which will ensure that the system meets the prescribed safety standards. Included within the scope of this study is the inspection of equipment to ensure that it conforms with submitted design information.

When the Pre-Operational Safety Study is submitted to Hq USAF, it will be accompanied by the system's safety rules, prescribing the controls and administrative procedures which will be applied to the system. These would include those safety rules to be applied in the transport of radioactive and fissile material.

The acceptance of the NRSSG's recommendations in the Pre-Operational Safety Survey by Hq USAF will constitute final approval for the airlift operations, as it must be preceded by all the other approvals (foreign governments, other government agencies, etc.) appropriate for the operations under consideration.

If, after this, any changes are made to equipment or operations (to include safety rules), special nuclear safety studies must be made to explore the safety implications. Depending upon the changes and the items upon which the changes are made, it may prove necessary to resubmit equipment designs to the AEC Operations Offices, the Bureau of Explosives, the Air Force Special Weapons Center or the Air Force Weapons Laboratory and again obtain their approval. In addition, special reviews and studies will be called for by the Deputy, The Inspector General if unsafe conditions are

revealed by operational experience.

b. Aerospace nuclear auxiliary power units

The Air Force nuclear safety program for aerospace reactor systems and radioisotope generator units is organized in the same fashion as it is for terrestrial nuclear power plants, under AFR 122-15. The safety of the transport operations should be regarded as only a portion of the overall safety program and safeguards designed for the operational utilization of the power unit.

The progression which would be followed is exactly the same. The first study would be the Site Evaluation Study which usually considers only the suitability of the site with respect to safety of operations, but which can be expanded to include consideration of container criteria, if necessary. The Initial Safety Study and then the Pre-Operational Safety Study would follow.

The AEC, most likely the Division of Reactor Licensing, could be expected to make its own analysis of the safeguards to be taken throughout the entire operational sequence. Other than this, however, it is unlikely that other organizations such as AEC field offices or the Bureau of Explosives would be called upon to analyze any portion of the transport operation except when a portion of the transport operations will be made utilizing civilian rather than military transport channels, in which case it would have to be proved to the Bureau of Explosives that the applicable provisions of Title 49 of the Code of Federal Regulations had been complied with. Of course, no such shipment should be made which provides protection less than that which would be provided by the ICC under Title 49 of the Code of Federal Regulations. Assistance regarding aircraft tie-downs can be obtained from the Air Force Special Weapons Center and regarding aircraft loading, from the Air Force Weapons Laboratory, as with the terrestrial nuclear power plants.

4. APPLICABLE EXPERIENCE AND REGULATIONS IN THE CIVILIAN TRANSPORTATION INDUSTRY

A discussion of the experience gained by civilian agencies involved in the surface and air transport of radioactive materials is included in this report for two reasons:

1) Most of the standards, procedures, and criteria that have been established for civilian surface transport are the result of extensive experience in those modes of shipment and will be applicable to the shipment of such materials via a new mode - military air. Also, civilian air transport experience with small radioactive shipments will prove instructive.

2) Very few shipments of radioactive material will originate and terminate at the air terminals, bases, or strips. The items will have to be transported from their point of origin to the airplane and from the plane to their destination by conventional means of surface transport. The standards for those mediums of transport as well as those for air transport must be met.

a. History

In 1936, some forty years after the discovery of radioactivity, the attention of transportation authorities in the United States was first drawn to the problem of shipping radioactive material via commercial transportation facilities. To be sure, other hazardous materials, such as explosives and toxic chemicals were already being transported on a routine basis, but radioactive packages were unique in that they would pose a "hazard-at-a-distance" even though packaged in a workmanlike manner. The occasion of this first concern was the growing suspicion, on the part of the manager of a film processing station in Chicago, that irradiation from unprotected shipments of medical radium, while the film was in the mails, was responsible for the periodic light density variations he was noticing in his product. Some sleuthing revealed that medical shipments could indeed have been responsible for this fogging of film. On July 13, 1936, the Acting Second Assistant Postmaster General (Mr. J. W. Cole) issued an order that stood, save only for two minor specific exemptions issued subsequently, until April 1949 as the basic guidance for the domestic shipment of radioactive materials by mail. The headline on the order reads:

"RADIUM, THORIUM OR ANY OTHER RADIOACTIVE SUBSTANCE, OR ANY MATERIALS CONTAINING RADIOACTIVE SUBSTANCES, SUCH AS POWDERS, CONTAINING RADIUM OR THORIUM, LIQUIDS CONTAINING RADIATION EMANATION, RADIUM SALTS, RADIOACTIVE MINERALS, OR ANY RADIOACTIVE MATERIAL WHATEVER, NOT PERMITTED IN THE MAILS."

The order is actually scientific nonsense in that every known material, be it animal, vegetable, or mineral, contains some amounts of radium and thorium. Likewise, all objects containing potassium, rubidium or any other of the naturally occurring radioactive elements would be excluded. Obviously, this was not the intent of the order but such would be a literal interpretation stemming from the crude specification.

This little episode is related, not only because it is historically interesting, but because it represents a frequently occurring reaction to the problem of shipping radioactive materials. Certainly had not this order been circumvented and finally repealed a great many people would have been deprived of the benefits obtained through the use of radioisotopes in radiography, medicine, and all other types of research. Here, as in everything else, the risk involved must be weighed against the benefit to be accrued. For the most part, this principle has been adhered to in the shipment of radioactive materials.

The Railway Express Agency, at the request of the National Cancer Institute, filled the void that existed as a result of the Post Office Department's refusal to handle "radioactive" parcels. A table was compiled listing the minimum lead shielding as a function of the amount of radium (0-600 mg) in a package and a fifteen-foot separation was maintained, in boxcars, between the packages and any X-ray film. The average total exposure at fifteen feet was 11 milliroentgens (see appendix II for an explanation of radiation units) with a maximum of 14.9 mr and a minimum of 7.3 mr. Packages could meet these specifications and yet have a radiation level as high as 8,000 mr/hr at the surface of the package and a gamma-ray intensity which delivered over 20 mr/hr at one meter (e. g., with 200 mg Ra in 1.5 inches of lead). All other gamma-emitting substances had to be labeled "Radium" and the regulation recognized no other active substances.<sup>8</sup>

With the advent of the Manhattan Engineer District the amount of radioactive material which had to be transported from one site to another became colossal. The problem was minimized by very tight security procedures and extreme amounts of lead shielding.

In 1946, when Oak Ridge started shipping isotopes to hospitals and universities, the same conservative principles of over-shielding during shipment were maintained as an interim policy until the Interstate Commerce Commission could formulate and enact new regulations. During this time radioisotope users were forced to pay extremely high freight charges on their purchases. It was not uncommon for a user's express charges to be higher than the cost of the isotope; this restricted much early experimental work.

Before discussing the transport regulations currently in effect, one last historical item should be covered and that is the early history of radioactive material in air transport.

During the war, several important research projects required the use of isotopes as radioactive tracers. As the work of the Manhattan Project was classified, the only sources of these isotopes were cyclotrons. Much of the work involved the use of short-lived isotopes such as  $\text{Cl}^{38}$  and  $\text{Na}^{24}$  which could be transported from the cyclotron site to the laboratory only by air if sufficient residual activity for the experiment was to be available. Special arrangements were usually made with airline and airport personnel and the shipments were made successfully. In July 1943 a mistake by ground handling personnel resulted in an estimated dose to a pilot of 35 mr. While this is a very low dose, it was regarded as proof that better defined procedures were required.

Air Express Tariff No. 8, Supplement 5, was then drafted (also known as Supplement No. 5 to CAB No. 22). It specified, for airlift in DC-3 aircraft (which have a cargo compartment in the tail), that gamma-emitting packages should not produce a dose greater than 14 mr at a distance of 30 feet during the time of transportation. These packages had to be marked: "Do not place in the same compartment with undeveloped films or mail." On the other hand, pure alpha and beta emitters were required to have 1/32 of an inch of lead around them, but required no special marking or segregation from other cargo. Airlines which flew planes such as the Lockheed Lodestar, which had only one cargo bin, could not accept gamma-emitting packages. This tariff was altered during its lifetime but has now been completely replaced by CAR Revised Part 49 of Title 14 of the Code of Federal Regulations.

b. Present ICC regulations

The Interstate Commerce Commission (ICC) is responsible for the formulation of rules and regulations governing the transportation of explosives and other articles. The ICC is authorized to call upon the Bureau of Explosives of the Association of American Railroads not only for the preparation of such regulations, but also for their execution after adoption by the ICC.

The Interstate Commerce Regulations covering the Transportation of Explosives and Other Dangerous Articles include eight parts of Title 49 of the Code of Federal Regulations, as follows:

- Part 71 - General Information & Regulations
- Part 72 - Commodity List of Explosives and Other Dangerous Articles
- Part 73 - Regulations Applying to Shippers
- Part 74 - Regulations Applying Particularly to Carriers by Rail Freight
- Part 75 - Regulations Applying to Carriers by Rail Express
- Part 76 - Regulations Applying to Carriers in Baggage Service
- Part 77 - Regulations Applying to Shipments Made by Way of Public Highway
- Part 78 - Shipping Container Specifications

Part 72, Section 5, specifies that: "All radioactive materials are classed as poison, class D, and are properly shipped as 'radioactive materials.'" The most dangerous articles such as lewisite, mustard gas, hydrocyanic acid, etc., are classified as Class A poisons; the less dangerous such as arsenical compounds, mercury compounds, aniline oil, certain fumigants, etc., are classified as Class B poisons. Class C poisons include tear gases and other skin irritants. The Class D poison designation was added, to consist entirely of radioactive substances and formulations when present in sufficient amount to be potentially dangerous. There is, at present, no Class E poison.

For the purpose of parts 71-78, radioactive materials are divided into three groups according to the type of rays emitted at any time during transportation as follows:

**GROUP I** - Radioactive materials that emit gamma rays only or both gamma and electrically charged corpuscular rays. If, at any time during transportation, the gamma-ray (including X-ray) intensity at any surface of the finished package will exceed 10 mr/24 hours, the radioactive material is classified as Group I.

**GROUP II** - Radioactive materials that emit neutrons and either or both the types of radiation characteristic of Group I materials. (These will be composite sources of reasonably long-lived alpha sources mixed with boron, lithium, or beryllium or a source of high-energy gamma rays mixed with deuterium or beryllium, as all known radioactive isotopes which spontaneously emit neutrons have half lives shorter than one minute.)

**Group III** - Radioactive materials that emit electrically charged corpuscular rays only; i. e., alpha or beta, etc., or any other that is so shielded that the gamma radiation at the surface of the package does not exceed 10 milliroentgens for 24 hours at any time during transportation.

Group III packages are marked with a special blue label, in contrast to the red label required for Groups I and II.

The specification noting that the acceptable level at "any time during transit" for Group III is necessitated by the fact that some radioisotope daughters which may be formed during transit emit a stronger gamma flux than the parent.

Some of the more salient features of parts 71-78 follow:

(1) Special specifications or allowances are made for the following items:

(a) Shipments of more than 2 curies of radium, polonium or other members of the radium family or more than 2.7 curies of any other radioactive substance packed in one outside container, except that mentioned below.

(b) Shipments of more than 300 curies of cesium 137, cobalt 60 or iridium 192 packed in one outside container.

(c) Packages for which it can be proven that there will be no leakage of materials under conditions normally incident to transportation, which will not contain more than 0.1 millicurie of radium, polonium, strontium 89 or 90, or barium 140 which disintegrates at a rate of more than 5 million atoms/second or that amount of any other radioactive substance which disintegrates at a rate of more than 50 million atoms/second, and which will emit not more than 10 milliroentgens for 24 hours of gamma radiation and no alpha, beta, or neutron radiation. (These packages are exempt from prescribed packaging, marking, and labeling requirements.)

(d) Shipments of electronic components of which radioactive materials are a part.

(e) Shipments of manufactured articles (other than liquids) such as luminescent instrument dials.

(f) Shipments of slightly radioactive ores, residues, etc. (which will be discussed in some detail, later in this report).

(g) Carload lots of low-activity freight.

(2) Radioactive materials that present special hazards due to their tendency to remain fixed in the human body for long periods of time must, in addition to the packaging previously described, be packed inside metal containers specification 2R, or another container approved by the Bureau of Explosives.

(3) All radioactive materials must be so packed and shielded that "the degree of fogging of undeveloped film under conditions normally incident to transportation (24 hours at 15 feet from the package) will not exceed that produced by 11.5 milliroentgens of penetrating gamma rays of radium filtered by 1/2 inch of lead."<sup>7</sup>

(4) The design and preparation of the package must be such that

there will be no significant radioactive surface contamination on any part of the container.

(5) The smallest dimension of any outside shipping container for radioactive materials must be not less than 4 inches.

(6) All outside shipping containers must be of such design that the gamma radiation will not exceed 200 milliroentgens/hour or equivalent at any point of readily accessible surface. Containers must be equipped with handles and protective devices when necessary in order to satisfy this requirement.

(7) Radioactive materials falling into Group I, whether liquid, solid, or gaseous, must be packed in suitable inside containers completely surrounded by a shield of lead or other suitable material of such thickness that at any time during transportation the gamma radiation at one meter from any point on the radioactive source will not exceed 10 milliroentgens/hours.

(8) Radioactive materials falling into Group II, either liquid, solid, or gaseous must be packed in suitable containers so that the radiation measured at right angles to any point on the long axis of the shipping container will not exceed:

- (a) Gamma radiation of 10 mr/hr.
- (b) Electrically charged corpuscular radiation which is the physical equivalent of 10 mr/hr of gamma.
- (c) Neutron radiation which is the physical equivalent of 2 mr/hr of gamma.
- (d) Total equivalent radiation not to exceed the 10 milliroentgens/hour value, if more than one of the three above mentioned types of radiation exists.

(9) Liquid radioactive materials in Groups I, II, or III must, in addition, be packed in tight glass, earthenware or other suitable inside containers. The inside containers must be surrounded on all sides and within the shield by an absorbent material sufficient to absorb the entire liquid contents and of such a nature that its efficiency will not be impaired by chemical reaction with the contents. If the container is packed in a metal container

specification 2R or other container approved by the Bureau of Explosives, the absorbent cushioning is not required.

(10) Radioactive materials Group III, liquid, solid or gaseous must be packed in suitable inside containers completely wrapped or shielded with such material as will prevent the escape of primary corpuscular radiation to the exterior of the shipping container, and secondary radiation at the surface of the container must not exceed 10 milliroentgens per 24 hours, at any time during transportation.

(11) Sections 75.655 and 77.841 limit transportation by one car or vehicle or storage in one place to 40 radiation units. Section 73.414 defines 1 radiation unit as equal to "1 milliroentgen per hour at 1 meter for hard gamma radiation or the amount of radiation which has the same effect on film as 1 mr/hr of hard gamma rays of radium filtered by 1/2 inch of lead." The number of radiation units is then a measure not of the quantity of radioactive material in a package, but rather of the gamma radiation emanating from the package.

(12) Part 77 specifies that a container of radioactive material bearing radioactive material, red label (Group I and Group II, class D poisons) must not be placed in vehicles, terminals, or other places closer than 3 feet to an area which may be continuously occupied by passengers, employees or shipments of animals. When more than one such container is present, the distance from occupied areas must be computed from a table in subparagraph 1 of section 77.841.

(13) No motor carrier may transport any radioactive material, poison, class D under these regulations in or on any bus while engaged in the transportation of passengers except where no other practicable means of transportation is available, according to section 77.870.

(14) The ICC packaging, labeling, and placarding regulations previously discussed are waived for the Atomic Energy Commission provided each shipment is escorted by personnel specially designated for that purpose by the Atomic Energy Commission. It is evident that the counting of placarded cars or labeled shipments leaving Atomic Energy Commission establishments might provide data on production activities which would constitute a breach of security. Military airlift may well necessitate similar types of precautions.

c. Present CAB regulations

The transportation of radioactive materials by (nonmilitary-controlled) air is regulated by the Civil Aeronautics Board. Its Civil Air Regulations (CAR's) covering the Transportation of Explosives and Other Dangerous Articles constitutes Part 49 of Title 14 of the Code of Federal Regulations. Many of the Civil Air Regulations applying to the shipment of radioactive materials - especially those applying to packaging, marking, or labeling of such materials are based upon ICC regulations. Comments on the ICC Regulations will not be repeated. The additional, salient points made in the Civil Air Regulations are:

(1) In addition to the packaging requirements previously discussed, containers for liquids must be securely closed and of sufficient integrity to prevent any leakage or distortion of the containers caused by change in temperature or altitude during transit, and so filled as to provide adequate outage.

(2) CAR 49.55(c) concerns stowage aboard aircraft, and is the only provision of the Civil Air Regulations which differs from the ICC Regulations (ICC 655(j)). The flight time is invariably shorter than the 24-hour transit time upon which distance tables for ground transportation are based. Also, flight crews are limited to a maximum of 85 flying hours per month. Accordingly CAR 49.55(c) provides the following table for the minimum separation between flight personnel or passengers and Group I or Group II parcels measured, in the case of air regulations, from the nearest edge of the nearest radioactive container.

TABLE FOR PERSONNEL SEPARATION<sup>8</sup>

Total no. of "units" (mr/hr)	Minimum distance to crew members & passengers (feet to nearest edge of nearest Group I & II parcel)
0-2	1
3-5	2
6-10	3
11-20	4
21-30	5
31-40	6

(3) The separation to be maintained between Group I and II parcels and undeveloped film shipped by air express or by air freight is given in part 49 and is such that irradiation will always be less than the standard value of 11.5 mr for a 24-hour period.

d. Present US Mail regulations

Except that the quantity limitation of ICC regulation 73.367(a)(2) is applied also to manufactured articles, those parcels of radioactive material which are exempt from specification packaging and labeling under the ICC Regulations are not acceptable in the mails. For regulatory purposes, there is no distinction made between the different classes of mail. First class mail, second class mail, air mail, parcel post and all others are regarded without distinction in this sense.

e. Present Coast Guard regulation

For transportation by water, there is a divided responsibility. The ICC Regulations determine the packaging and labeling of acceptable articles, but the acceptability, handling, and stowage aboard ship are the responsibility of the U. S. Coast Guard. The U. S. Coast Guard Regulations are given as Title 46 Part 146 of the Code of Federal Regulations. To the extent that any particular set of ICC regulations for ground transport are applicable to stowage aboard inland, coastal or transocean vessels, the Coast Guard generally adopts the principles of the ICC regulations. In the case of import shipments, parcels of dangerous articles must conform to the ICC ground regulations before being allowed to move out of the port area by ground transport. Export shipments must conform to the ICC packaging and labeling regulations in order to be transported to the port area. Aboard ship, packaging and labeling must conform to either the ICC regulations or the regulations of the country of destination.

f. Present Atomic Energy Commission regulation

After the second World War, in 1947, there was some question as to just who had jurisdiction over the transport of dangerous, radioactive material. The question, debated by the legal departments of the ICC and the AEC was whether the Act of Congress authorizing the ICC to regulate the transportation of dangerous articles was or was not "superior" to the Act of Congress establishing the Atomic Energy Commission's jurisdiction in the

field of radioactivity and nuclear fission. It was finally decided that the ICC has jurisdiction and the first ICC regulations were adopted on October 24, 1947, and went into effect on January 21, 1948.

The Atomic Energy Commission does, however, have responsibilities stemming from its basic charter in the transportation of certain radioactive materials which should not be overlooked. In the interest of protecting public health and safety, the Atomic Energy Act of 1954, as amended, requires the Atomic Energy Commission to exercise regulatory control over organizations and individuals who own and operate nuclear installations and possess and use source material (natural uranium and natural thorium); fissionable or fissile material (enriched uranium and plutonium); byproduct material (radioisotopes); and otherwise engage in the peaceful uses of atomic energy. The Department of Defense is obviously excluded from this control.

In discharging its regulatory responsibility, the AEC has developed and put into effect a system of regulations governing the construction and operation of reactors and other nuclear installations, and the possession, use, and disposal of radioactive materials. Briefly, the regulations state that persons within the United States (except the DOD) shall not transfer, acquire, possess, or use any reactor or source, fissionable material, or radioisotopes, except as authorized by a license issued by the AEC.

The definition of responsibilities between the AEC and the ICC as regards the transportation of fissionable and radioactive materials is based upon the fact that the AEC is not equipped nor does it have the authority to regulate interstate commerce (and perform all the responsibilities which accrue to an agency that does), while it does have the facility to establish procedures and standards for the utilization of atomic energy and for the protection of the public from radiation hazards. The ICC rather, by its very nature, is the proper vehicle through which to publish and enforce standards which must be applied to the transportation of hazardous materials via the avenues of interstate commerce. The regulations published by the ICC reflect, of course, established AEC philosophy on the handling of radioactive material by non-radiation workers and exposure of the general population to radiation hazards in unrestricted areas.

The regulations published by the AEC prescribe performance type safety standards and requirements for protecting the licensee's employees and the public against radiation hazards. These standards are designed to conform with the recommendations of recognized technical authorities, such as the Federal Radiation Council and the National Committee on Radiation Protection and with the AEC's safety experience in its own operations.

Occupational radiation exposure (i. e., the exposure of radiation workers) is safeguarded by the licensee through his control over access to his installations and by the direction of the activities of individuals within such installations. Nonoccupational exposure is controlled by limiting to safe levels the quantities of radiation released by the licensee to areas not under his authority.

Among the regulations which the AEC has promulgated or issued as proposed rules under Title 10 of the Code of Federal Regulations are detailed licensing regulations:

- Part 30 - Radioisotopes
- Part 40 - Licensing of Source Material
- Part 50 - Licensing of Production and Utilization Facilities
- Part 70 - "Licensing of Special Nuclear Material" which deals with fissionable material
- Part 71 - Shipment of Special Nuclear Material (fissionable)
- Part 72 - Protection Against Radiation in the Shipment of Irradiated Fuel Elements

In particular, part 70 specifies container sizes for isolated packages containing relatively small amounts of 100-percent fissionable uranium or plutonium and allowable arrays for those packages in storage.

Part 71 specifies broad policy regarding the small shipments of fissionable material, enforced so that accidental criticality is precluded. Neither part 70 nor part 71, which are discussed in more detail in section 5a (2)(b) of this report, offers appreciable guidance pertinent to the situations which this report addresses itself to.

Part 72 does, however, offer some applicable guidance. It specifies, for AEC licensees, the cask design criteria (for ground transport) and the

procedures required to obtain commission approval of a cask design. This part will be discussed in detail in the chapter in this report on container criteria, as many of the standards established in part 72 should bear upon cask designs for air shipment.

g. The safety experience accumulated in the shipment of radioactive materials

Since the early days described in this chapter, the shipment of radioactive materials has become a well regulated, commonplace experience for the AEC and the American transport industry. It is estimated, for example, that in the period 1946-1960, Oak Ridge National Laboratories (ORNL) made over 143,000 shipments of radioactive material, the sales value of which was in excess of \$20 million. Commercial firms' shipments and sales figures are not available but are known to be much greater than the ORNL figures. There are, at present, more than 6,500 AEC licenses in this country and agencies in 65 foreign countries to whom these shipments are made.<sup>9</sup>

The AEC reports that, in the five-year period of 1957-1961, an accident rate of approximately 0.17 accident per 1,000 shipments was compiled (a total of 47 accidents with an average of 47,000 shipments per year).<sup>10</sup> If one estimates that the average shipment is between 100 and 1,000 miles in length, this then works out to be a rate between 1.7 and 0.17 accidents per million miles. This is somewhat below the rate for truck accidents and the average frequency for all commodities. If one considers only those off-site accidents in which packaging was breached, one finds only 15 such accidents during the five-year period, for a figure of 0.64 to 0.06 accident per million miles. Of the 15 cases of packaging breaches only two resulted in the mechanical failure of the container and one resulted in the failure of the container by fire.

The most common failure, as would be expected, was the leakage of liquid. Of all the accidents reported, no significant contamination or exposure of personnel was reported.<sup>11</sup>

It should also be noted that, while figures on the volume of fissionable materials handled and transported are not available, the shipment of special

nuclear material has not yet resulted in a single incident involving accidental criticality.

## 5. TECHNICAL ASPECTS OF SHIPMENT

### a. Container criteria

#### (1) Spent fuel elements

It is to be remembered that the radioactive decay of the fission products is the prime source of problems in the packaging and shipment of irradiated reactor fuel. When one considers this fact alone, the question that comes to mind is: "Why not just let the irradiated fuel elements 'cool' (in the radioactive sense) indefinitely, or at least for several years?" Their activity is continually decreasing and they are becoming less and less of a headache to handle as the shielding requirements are lessened. Unfortunately, the situation is not that simple but is complicated by another fact: the high cost of enriched uranium and radioisotope material. The Atomic Energy Commission commonly requires payment of interest charges (or use charge) of 4-3/4 percent per year on the total value of the fuel inventory for the complete period it is out of their hands.<sup>12</sup> This means that an idle PM-1 core (irradiated conditions) represents a loss to the government of at least \$13,500 per year. At the present time many proposals are being made to gradually step up this use charge to 100 percent of the value, allowing civilian ownership of the fuel and thus setting the civilian nuclear power industry on a self-sufficient basis. While the military may not be charged by the AEC for use of the fuel inventory it is, nonetheless, a loss of revenue for the government which should be taken into account.

Also, the radioisotope fission products which can be recovered from the irradiated fuel elements are becoming more and more valuable for diversified applications. (Isotopes making major contributions to fission product activity as a function of time are shown in figure 7.) Although certain isotopes of value do actually build up their fraction with time (due to the transmutation of other isotopes), all eventually decay to stable states. The longer one waits to recover the isotope fission products the less there is to recover and this, too, constitutes the loss of valuable material.

It is the responsibility of the agency sponsoring the plant's development to make a determination of the optimum cooling period, balancing the loss to the government resulting from an unnecessarily long cooling period against the cost of the shipment of an unnecessarily heavy cask to the plant site, from there to the Idaho Chemical Processing Plant or Savannah River Plant, etc. As this determination is highly dependent upon the circumstances of the plant design, location, etc., no example is offered. Figure 8 (from Reference 13) is included as an example of the decline of shielding requirements with time, however, and one may see how dependent the shielding requirement is upon the time the fuel elements are allowed to cool.

The assumption is made throughout this study that the spent fuel elements will be continuously immersed in water. The great majority of the consumer terrestrial nuclear power plants in the United States and all of operational military plants are of the pressurized water or boiling water variety. Once the core loading is performed the fuel elements are completely immersed in water, during their operational life, during transfer to the cooling pit, during transfer to the shipping cask, etc. The matter is, of course, quite different in the United Kingdom, Australia, or wherever gas-cooled reactor technology prevails.<sup>14</sup> In the United States with the water-cooled technologies, this continuous immersion is a fact of life, however. Even were it not, though, there are certain advantages to shipping irradiated fuel elements in water.

As will be discussed later, one mandatory item of design philosophy for irradiated fuel casks is that they must allow sufficient heat dissipation to keep the fuel elements well below their failure temperature with no coolant in the cask. It then might be argued that, since the cask must be designed to keep the elements somewhat below the danger point, without water coolant, one should ship the elements in a dry cask. There are two reasons why this should not be done.

First, the temperature at which irradiated fuel elements begin to leak fission products is not well specified. It is known, however, that the lower the temperature at which such fuel is kept, the less possibility there is of failure. For this reason it seems wise to maintain the fuel at as low a temperature during shipment as is conveniently possible. Water-filled casks can maintain fuel temperature as much as 400 degrees F cooler than in a corres-

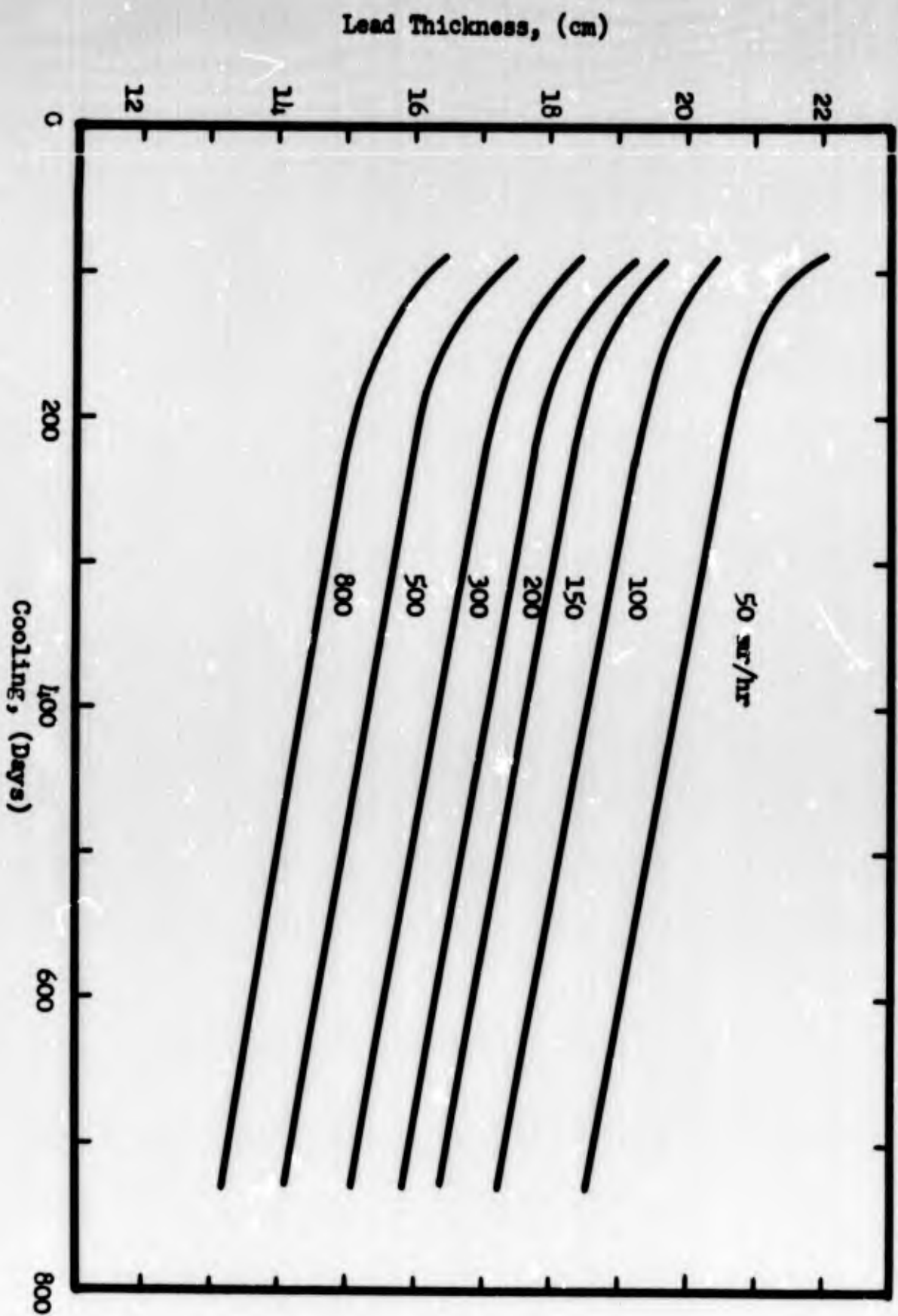


Figure 8. Cask wall thickness as a function of cooling time for several surface dose rate - 25 SM-1 elements

ponding dry cask. The use of water instead of air for coolant is the main reason for this.

The second, primary reason for using water as a coolant is that at the chemical processing plant the cask filled with fuel will be lowered into a tank of water for handling. If a dry cask is used without precooling, water striking the hot elements (500 to 600 degrees F) may well thermally shock them to the extent that some will begin to leak fission products in the receiving facility of the processing plant. Addition of gradual precooling facilities would cost more than the very small shipping saving resulting from the elimination of water.<sup>13</sup>

Throughout the discussion within this report of the air transport of radioactive materials, it is assumed that the shipment will be accompanied by a qualified courier, much the same as AEC special weapons shipments are accompanied by couriers. The duties of this courier will be to control personnel exposure and to ensure compliance with the film badge program set up for the aircrew and loading crews, to monitor the temperature, radiation levels and integrity of the cask, and, in the event of a cask failure, to monitor the contamination, ensure minimum exposure to it, and direct any decontamination or other remedial action until such time as the designated emergency team arrives (if any). This man must be a qualified health physicist proficient in the use of radiac survey instruments (see appendix IV) and experienced in radiation control programs. Most probably he will be a crew member of the health physics staff of the nuclear plant from which the irradiated fuel is being shipped. As it will be several years before such shipments are made on a frequent basis, this requirement should not place an appreciable drain upon nuclear plant crew resources.

Finally, before entering into a detailed discussion of the proposed criteria for irradiated fuel element containers a word should be said about determining compliance with such criteria. One should first bear in mind that these containers are rather costly items. The cost of the materials alone, for a cask such as that designed for the PM-1 core (figure 9) runs close to \$5,000 to say nothing of the cost of fabrication which is undoubtedly a great deal more (Poindexter<sup>13</sup> estimates a total cask cost of one dollar per pound for lead). Hence, the testing of such items to include such tests as the determination of

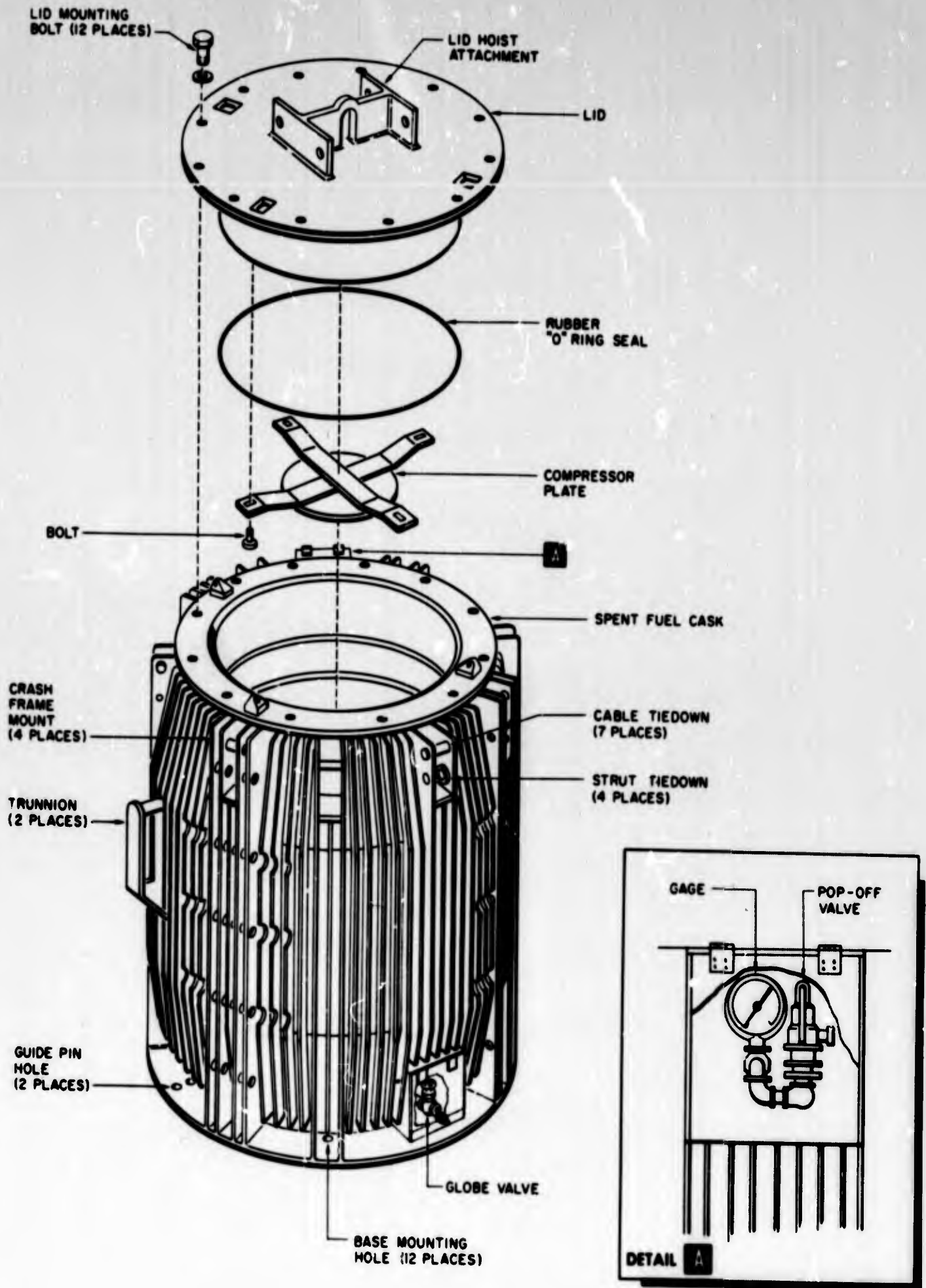


Figure 9. PM-1 spent fuel shipping cask

the mechanical integrity upon 15- or 30-foot drops onto "unyielding" surfaces, or fire tests, is rather expensive. However, when such specifications are made, one must combat the tendency to engage in an "orgy of testing" as Messenger and Fairbairn<sup>15</sup> have put it or to adopt the testing philosophy reported by Mr. Dugan<sup>14</sup> (of Brookhaven National Lab) of an Indian rajah who drove elephants off a cliff just to see them bounce.

Messenger and Fairbairn<sup>15</sup> have made a most logical statement in the philosophy to follow in determining compliance with a given set of packaging specifications:

"The sponsor of a packaging design must demonstrate, to the satisfaction of the approving authority concerned, that the packaging design is adequate in relation to:

prevention of release of contents of package (containment)

limitation of external radiation from package (shielding)

dissipation of heat generated by contents of package

**AND**

when the packaging is to be used for fissile material, prevention of a criticality accident.

... He may endeavor to achieve this by one or more of the following means, e. g.:

- a. By engineering assessment. (All assumptions made for the purpose of such assessment shall be stated.)
- b. By tests of models of packaging details or mock-ups representing methods of construction.
- c. By extrapolation from test results for similar designs or designs employing similar construction features.
- d. By reference to accident experience with packaging of similar design and the results of periodic inspection of such packages.
- e. By any other reasoned argument or evidence, or failing these,
- f. By actual tests of samples of packaging made to the design."

It may be seen that some of these methods of attack which may be used to obtain packaging approval are not completely a matter of mathematical engineering analysis but are also something of an art. In particular,

the extrapolation of data from packages of similar design and the testing of models are not altogether straightforward affairs. As regards the testing of models, however, there are certain laws of scaling and similitude which may be followed. In the drop testing of models, for instance, the test and test item may be scaled down so that the mechanical strain induced in the test model and in a full-sized cask are identical. There is, however, some lower limit imposed upon the scaling one can perform by details such as stress concentrations, welds, fins, etc., and the fact that, in certain metals, the stress-strain properties are strain-rate sensitive.<sup>14</sup> Suffice it to say that to avoid the expense of full-scale testing, techniques must be adopted by both the sponsoring agency and the approval agency which require a high degree of technical judgment.

The reader is now urged to study in detail appendix III to this report, "Proposed Criteria for Irradiated Fuel Element Containers Intended for Air Shipment."

These criteria are essentially those of Title 10 of the Code of Federal Regulations, part 72: "Protection Against Radiation in the Shipment of Irradiated Fuel Elements" with certain modifications. In particular, military climatic and aircraft environments and marking are specified, the internal portions of the cask in contact with the coolant water must be stainless steel, and a health physicist escort is assumed.

Although the Department of Defense is not bound to the regulations which the Atomic Energy Commission establishes for its licensees, the standards in 10 CFR 72 are in no way compromised by the criteria proposed in this report. To ignore these standards would be to ignore the lessons which have been learned from the most extensive experience available anywhere in the transport of radioactive and fissile materials. Also, maintaining compatibility between air transport standards and AEC ground transport regulations enables the Department of Defense, if it so desires, to use normal channels of ground transport (i. e., those normally used by licensees).

The container criteria are presented in specification form for convenience. Although the first paragraph states they are binding upon any sponsoring agency desiring air transport of irradiated fuel elements they are,

in reality not. Rather, appendix III contains only the recommendations made by this author for such criteria. These criteria would become binding upon sponsoring agencies only after formal certification and adoption by higher headquarters.

(a) Nucleonics

As Messenger and Fairbairn have stated, the prevention of criticality is one of the four primary packaging considerations in the shipment of fissile materials. Indeed, it is the paramount consideration. The worst possible accident one could postulate for such an item would be an uncontrolled excursion, with its tremendous burst of streaming neutrons, electromagnetic and corpuscular radiation, steam explosion, and fuel element meltdown with resulting fission product release. Fortunately, nuclear criticality is a function of geometry and geometry can be well controlled, mechanically. Originally, the AEC philosophy was to forbid shipment of an entire core (appendix III, 2.1.1.); this is, of course, the easiest way to completely preclude the possibility of an inadvertent criticality, and is still recommended, wherever possible. There are two factors which have caused the shift in philosophy to also allow shipments of full cores, providing  $k_{eff}$  will never exceed 0.9 in the most reactive configuration, and with the maximum possible neutron moderation and reflection. First, cores (such as the PM-1 and PM-3A; see figure 1) are being designed as more integral units rather than merely arrangements of identical and easily removable fuel elements. This is particularly so for cores designed for small semitransportable military nuclear power plants and for fully mobile power plant cores (such as the ML-1 SNAP 2, and SNAP 10A reactors). (Shipping only a fraction of a critical mass, with these reactor cores, can be something of a problem.) The second reason for the inclusion of the  $k_{eff} = 0.9$  nucleonics criterion is cost. As may be seen from figure 9 or the picture of a cask proposed for 25 SM-1 fuel elements shown in figure 10, these casks are expensive and very heavy. It would obviously take two casks to ship one spent core (or two round trip shipments with one cask) if the 75 percent of a critical mass criterion was followed, and the cost of air transport would almost double. Actual cost records for air shipment to and from the DEW Line resulted in a charge rate of \$1 per ton mile.<sup>13</sup> Round trip air transport of a PM-1 cask, from the Idaho Chemical Processing Plant to Antarctica and back (15 tons, for

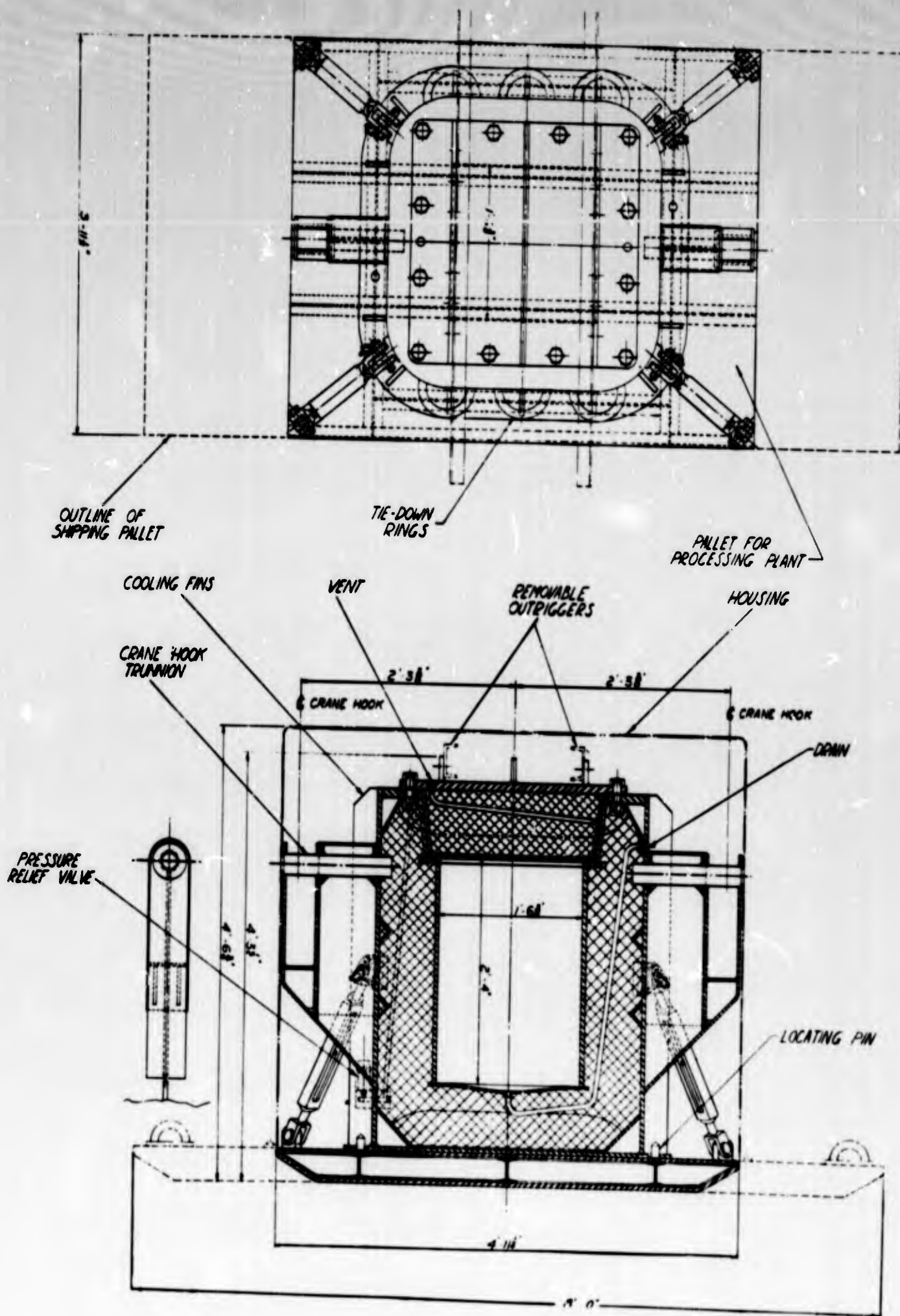


Figure 10. SM-1 spent fuel shipping cask

approximately 20,000 miles), would then run close to \$300,000. Certainly if measures can be safely taken, which will prevent doubling this figure for the shipment of a single irradiated core, they should be taken.

Paragraph 2.2.2. of the proposed criteria specifies that the fuel element cask must be designed for the most reactive possible loading that it could ever receive. This is in keeping with the design philosophy that calls for maximum reliance upon equipment and the minimum reliance upon correct operational procedures.

Paragraph 2.3.4. represents a change in the philosophy of the AEC. Formerly, the sponsoring agency was not allowed to take into account any neutron poisons that might be present in the core structural materials or fuel element cladding but with the 23 September 1961 publication of 10 CFR 72, this has been changed. Although not specifically stated in the criteria, there is also allowance for the introduction of poisons specifically inserted for the purpose of limiting criticality in shipment. Such inserted poisons must, of course, always be in their proper positions under the forces specified in sections 9 and 10 and the fire conditions specified in section 13. A good example of such a poison would be boron-stainless steel alloy plates with a 2 percent boron (by weight loading) such as those suggested by Poindexter<sup>13</sup> for the SM-1 fuel element cask shown in figure 10 or the .062-inch thick corrugated plates of 0.7 w/o natural boron-stainless steel proposed for the PM-1 spent core cask. A picture of a similar loading of such absorber plates in place in the PM-1 cask is shown in figure 11.

(b) Radiation shielding

One will notice, in reading section 3.1 of appendix III that no recommendations are made concerning shielding material. The first inclination is naturally to assume that lead is the ideal shielding material. Most people will naturally think lead is to be the shielding material for the simple reason that almost all the casks used to date have used lead. The PM-1 cask for instance, has 7-7/8 inches of lead on the sides and 8-1/4 inches of lead on the ends.<sup>16</sup> For gamma-radiation shielding the densest possible material is desirable. Also it must have a reasonably low cost and be easily fabricated into casks. Candidates, their densities and 1959 costs<sup>13</sup> are the following:

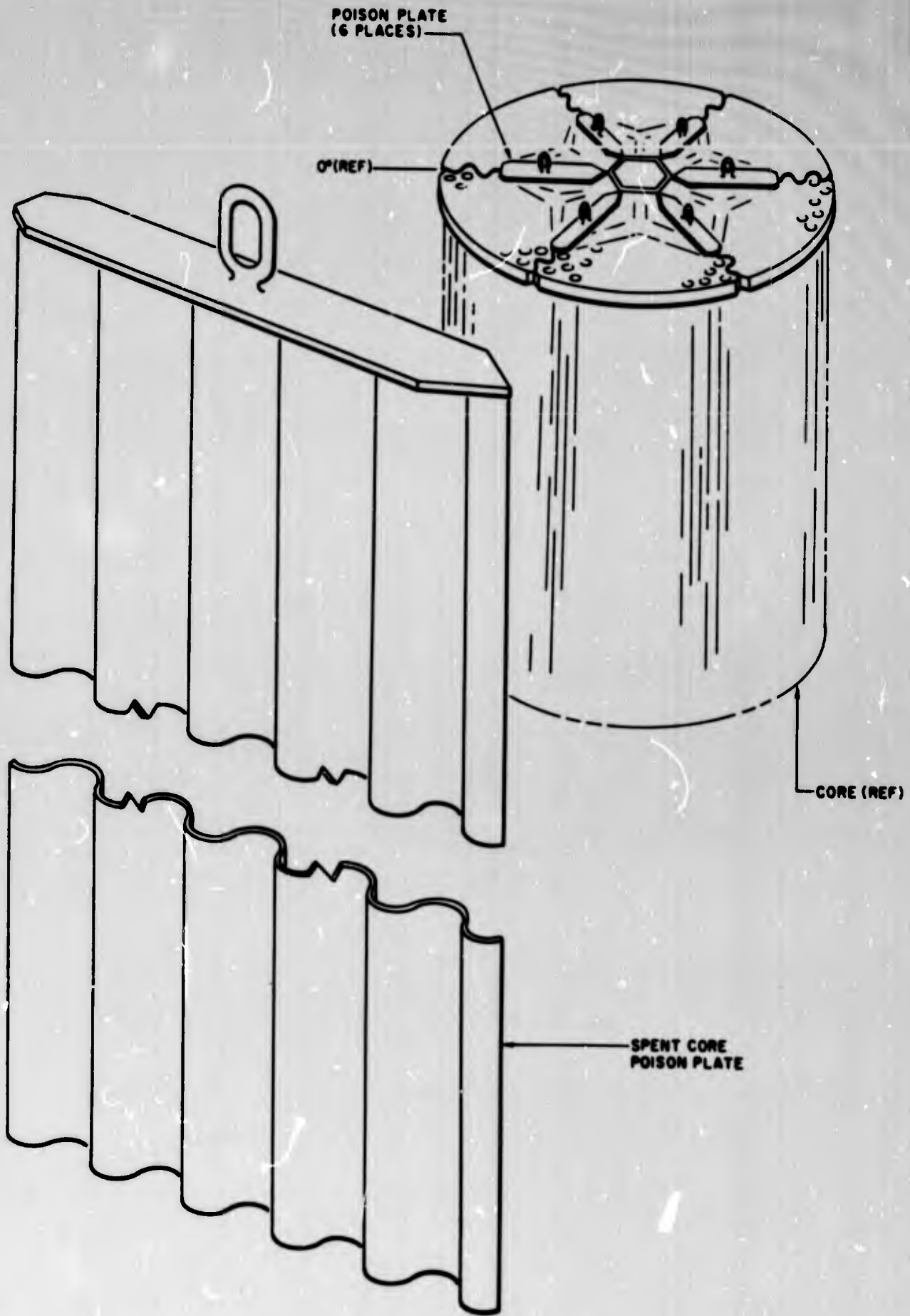


Figure 11. PM-1 spent core poison plates

<u>Material</u>	<u>Density (lb/in<sup>3</sup>)</u>	<u>Price (\$/lb)</u>
Steel	0.283	0.08
Bismuth	0.354	2.25
Lead	0.410	0.13
Thorium	0.419	19.60
Mercury	0.490	3.10
Uranium (depleted)	0.686	4.00
Tungsten	0.692	10.00

Although thallium, tantalum, rhenium, osmium and iridium are attractive because of their high densities, they have been rejected as shield materials because of their extremely high cost. Also no production facilities are available to fabricate these materials into casks. Because steel is cheap, it is considered as a shielding material even though it has a comparatively low density and is somewhat more difficult to fabricate than lead.

Bismuth is rejected because it is not only less dense than lead but it is more expensive.

Mercury is rejected as a shield material for air shipment because being a liquid, there is always the potential problem of leakage with the resulting loss of shielding.

Tungsten, though it has roughly the same density as lead, is rejected because it is considerably more expensive. Likewise, thorium is rejected as it costs almost 200 times as much as lead.

Depleted uranium is considered as a shield material because of its high density. It has the disadvantage that facilities and techniques for the production of shipping casks would have to be developed. The price of uranium is relatively high, but its high density makes it attractive as a shield material as it would result in smaller, lighter casks. Also, in considering the cost of uranium for such use the possibility should be borne in mind that the USAF might be able to obtain depleted uranium in the form of uranium hexafluoride from the AEC at Oak Ridge.

Lead, besides having a moderately high density has the additional features of low cost and ease of fabrication. Moreover, facilities

and techniques necessary for the production of lead casks are already available. Because of these facts, lead appears to be an attractive choice as a shield material for air shipment and has no special problems.

The total costs for lead and steel are fairly close, so the cost of the cask per pound must be evaluated. The cost of lead casks on a per pound basis is fairly well known from experience. Costs for steel casks are not as well known because there is no experience along these lines. Presumably the cask would be cast from carbon steel. As stated in paragraph 12.8 all inner surfaces which may come into contact with the liquid coolant will probably be of stainless steel, suitably masked from any dissimilar metal present in the cask. Either the steel castings must be enclosed in a fabricated stainless jacket and liner and be bonded to it in some fashion, or a stainless-steel surface must be deposited upon the base metal. A weld deposit method similar to that used for cladding the inner surface of carbon steel reactor vessels would probably be used. This is a rather expensive process. Perhaps a metal spraying technique could be used for covering the cask. In any of the methods considered a cost of 80 cents per pound of finished cask seems likely. In general, steel casks will be significantly heavier than lead or uranium and are hence excluded from consideration because of the higher shipping costs involved.

In considering the economic disparity that exists between the use of lead and uranium as a shielding material, uranium may be viewed in a more favorable light by making a few assumptions favorable to it. Poindexter<sup>13</sup> first assumes a cask cost of \$1 per pound for lead, 80 cents per pound for steel and \$8 per pound for depleted uranium. He then lowered his cost estimate of the uranium cask to \$4 per pound, assuming that the military could obtain depleted uranium in the form of uranium hexafluoride from Oak Ridge at this cost. Even with these assumptions (using a \$1 per ton mile transport figure for logistic distances of 1,500 nautical miles from the Idaho Chemical Processing Plant and considering a cooling off period of 360 days) the total shipping costs for a uranium cask run 6 percent higher than those for lead.

These additional shipping costs plus the fact that fabricating techniques for uranium are not as well known as those for lead, indicate the advisability of using lead in irradiated fuel element casks, in the near future.

For a particular shipping problem, however, it is recommended that the above type of analysis be re-run using up-to-date material prices and air transport cost figures and considering any advances that have been made in the techniques for fabricating either uranium or lead.

In order to reduce the radiation exposure level at the surface of the cask to the 100 milliroentgens per hour specified in paragraph 3.1, a sheet metal shroud (in effect moving the accessible surface farther out) may be firmly attached to the pallet, covering the cask in a fashion such as that shown in figure 12. The shroud must not, however, impair the heat dissipation as specified in section 4 of the criteria. Likewise, should the shroud be deformed or torn off as a result of the application of the forces described in section 9, the radiation levels at the newly accessible surface, assuming loss of liquid coolant upon the application of those forces, shall not exceed the 1 roentgen per hour at 1 meter level specified in paragraph 3.2 of the container criteria.

One operation which can be performed at the plant site will decrease the cask size and transport cost. This is the sawing off of unnecessary material at the extremities of the fuel elements (this is in cases where the fuel elements are handled individually as in the SM-1, SM-1A, and PM-2A as opposed to the PM-1 and PM-3A). Usually there are several inches on each end of such a fuel element of base metal (stainless steel, aluminum, etc.) which is used to shape the coolant flow pattern, provide the necessary mechanical interlock with grid plates, and thermally expand or contract through at least one of the grid plates with temperature variations. Since each pound of weight eliminated from the cask can mean a savings of \$20 on a round trip to the Antarctic and back, the elimination of these extra few inches of cask length can result in appreciable cost savings.

This discussion of shielding has been premised upon the fact that all of the shielding necessary to meet the specifications in paragraphs 3.1 and 3.2 of the criteria are integral to the cask design. If one is imaginative, other schemes can be postulated which would not require shipping as much weight as does the concept of having all the required shielding integral to the cask. For instance, one might handle the cask by semiremote means and the flight crew might be protected by a split, shadow shield (although this would have to be analyzed to see what the scatter dose from the air would be).

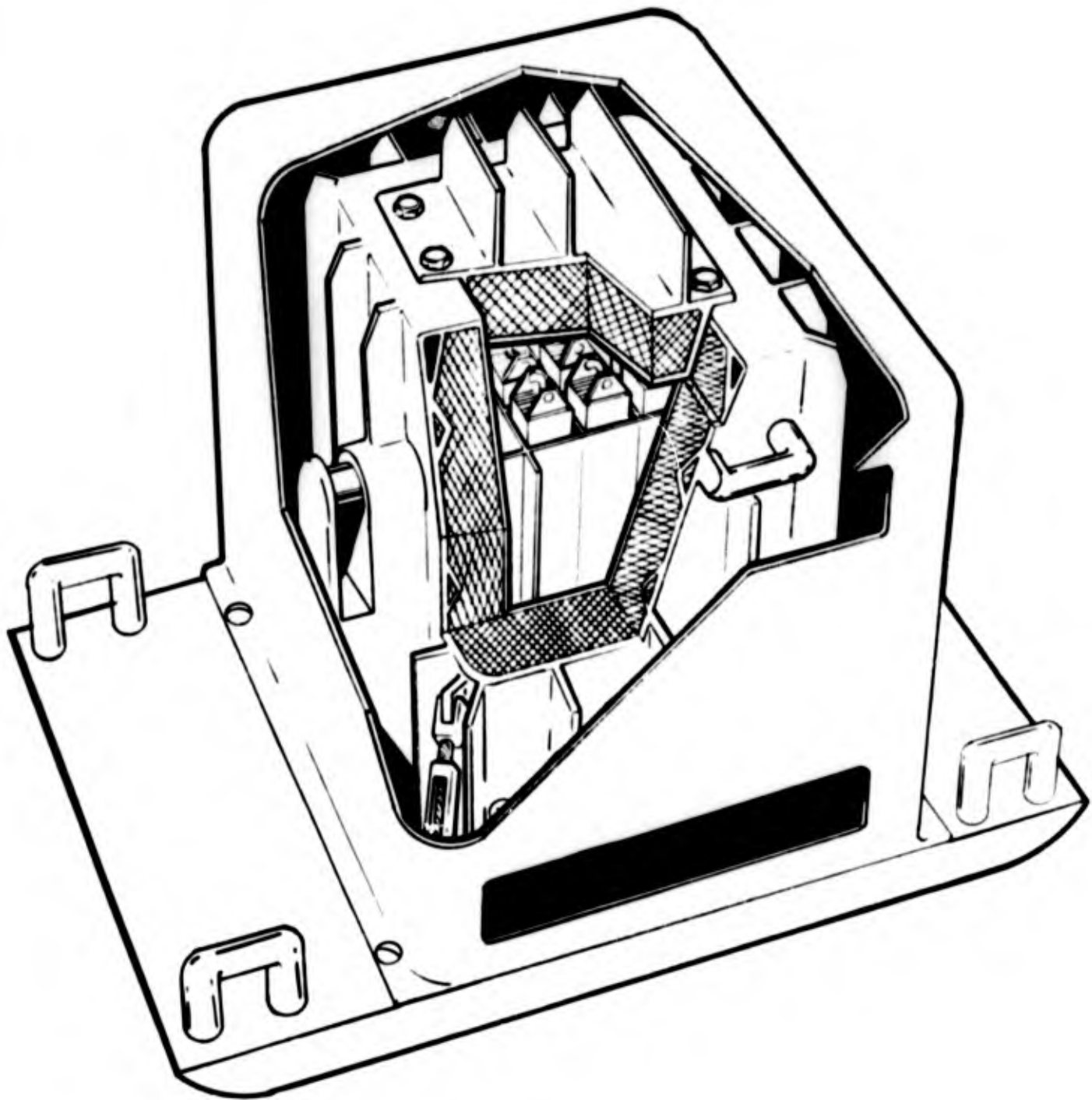


Figure 12. SM-1 fuel shipping package

Another way might be to have a removable outer shield which would be in place only during the loading and unloading operations. There are considerable drawbacks to such concepts, however. Aside from calling for extensive ground support equipment at both the point of origin and the destination, it would not be possible to ever ship the cask (loaded) by normal, AEC licensee type, transport facilities. Also the fact that radiation levels, when the cask reaches the re-processing plant must not exceed 200 mr/hr on contact and 10 mr/hr at 12 feet (see sub-appendix to appendix III) prevents the shipping agency from enjoying a very significant advantage by limiting the extent to which shielding may be decreased. Also one must remember that, wherever possible, safety will be designed into equipment and not into operations. Any sort of a split shield concept would compromise this philosophy. The integration of all the shielding required to meet the direct radiation standards into the cask walls is the safest and probably the most inexpensive concept for shipping irradiated fuel elements and it is highly recommended.

As specified in paragraph 3.6 the health physicist accompanying the shipment should make a radiation and visual survey of the cask before it is released from the point of origin.

(c) Heat dissipation

The specification of the minimum acceptable heat dissipation properties of an irradiated fuel element cask is not an item which is separate from the other specifications (radiation shielding, physical integrity, etc.) levied upon a cask designer. With improper heat dissipation the liquid coolant may boil, resulting in an overpressurization of the cask, in turn resulting in a leak and loss of the coolant, in turn resulting in higher fuel element temperatures and possible fuel element failure, in turn resulting in fission product release. Also, the higher fuel element temperature may cause the shielding material to melt and, if the shielding material specification is not adequate, this will result in loss of the shielding material and unduly high direct radiation levels. Obviously, the different specifications in the container criteria are very much interrelated; but if one were to place them on a scale of importance, heat dissipation would probably come second, after nucleonics and on a par with physical integrity. Of course, one cannot really break out heat dissipation

from the criteria without including section 14, Survivability in Fire.

As mentioned previously, the fission products are not atomically stable but are constantly decaying, mostly by the emission of beta particles and gamma radiation to stable states. Most of this emitted radiation is absorbed within the fuel elements and is converted to heat. It is this heat which must be transmitted to the surrounding environment at acceptable temperatures. One of the most obvious temperature constraints is that value which shall be allowed at the surface of the cask. Personnel, in loading, unloading and tying down the container will have to work in close proximity to the cask and they must be protected against burns resulting from accidental contact with the cask surface. The value of 180°F at any time during transport (including the hot desert conditions with solar heat load specified in Mil Std 210) given in 10 CFR 72 is used here. The AEC also recommends that upon the draining of the primary coolant the surface of the cask shall not exceed 350°F. This is not a very practical specification, first because the risks involved in determining compliance (the fuel element thermal shocking and risk of fission product release upon refilling the cask discussed previously) outweigh the value of the precaution and, secondly, because it is highly unlikely that the cask outside temperature will reach this value because of the explicitness of the specification contained in paragraph 4.2 of the criteria which allows the fuel element surface temperature in a dry cask to go up only 100°F above the value for the fuel element surface temperature in the cask properly loaded with liquid coolant. It is hard to conceive how the fuel element temperature could go up only 100°F and the cask surface temperature could go up 170° (350-180 degrees) as the fuel element temperature is the driving parameter. Therefore, this specification is omitted. The 350° figure has meaning only in that it is well below the charring or ignition point of wood.

The specification in paragraph 4.1.2.3 that the liquid primary coolant remain at all times at least 20°F below its boiling point is made to preclude the loss of heat transfer capacity resulting from a loss of coolant or a large pressure buildup within the cask due to gas. It is a well-known fact that the boiling point temperature decreases with altitude as a result of the lower prevailing pressure. The decrease at ambient pressure for that altitude is given<sup>13</sup> as

<u>Altitude (ft)</u>	<u>Boiling point of water (degrees F)</u>
0	212
10,000	194
20,000	176
30,000	157
40,000	137
60,000	103

If one considers ambient conditions, however, the temperature of the water in the cask also drops considerably. In a 25 SM-1 fuel element cask design made by Poindexter in reference 13, the cask water temperature (assuming the cask is exposed to ambient pressure and temperature) is

<u>Altitude (ft)</u>	<u>Cask water temp. (degrees F)</u>
0	119
10,000	83
20,000	48
30,000	12
40,000	-7
60,000	-7

This is obviously because the temperature of the ambient atmosphere to which the heat is being rejected falls also. As regards the effect of aircraft altitude upon cask coolant, this discussion is largely academic, however. Should the cask be flown at altitudes above 25,000 feet AFR 60-16 requires that the aircraft be pressurized. As the outside temperature at 25,000 feet ranges (approximately) from +10°F to -70°F the aircraft also will be heated for the comfort of the crew and so the cask will not "see" ambient pressure above 25,000 feet and will not see ambient temperatures above those which correspond to altitudes much lower than 25,000 feet.

As regards paragraph 4.1.2.2, which specifies that anti-freeze be loaded in the cask to correspond to the ground low temperature conditions given in Mil Std 210, one might ask if it is not necessary to be more rigorous than that because of the adverse temperatures at altitude. The answer is no. While it is true that cabin pressurization and heating systems have been known to fail (in aircraft), the minimum conditions specified in Mil Std 210 for world-wide use ( $-65^{\circ}\text{F}$ ) are much below those which any aircrew would tolerate for long. If cabin pressurization and/or heat were lost at altitude one may be quite sure that the aircraft commander would quickly descend to a lower and more comfortable level. Obviously with loss of cabin pressurization the cask will see a much lower pressure, almost instantly (and this will be discussed later) and a lower temperature. The cask need not be specified for this temperature, however, because its tremendous thermal mass will preclude any but the smallest amount of liquid cooling before the aircraft commander descends to an altitude where the ambient is much less than the Mil Std 210 value.

The use of antifreeze must be made to meet the low temperature requirements of the criteria. This will, in general, raise the boiling point of the water somewhat. As regards the nature of the antifreeze to be used, organics should be avoided. Experience with ethylene glycol at the Idaho Chemical Processing Plant, for instance, indicates that it is totally unsuitable for use with irradiated fuel elements as it decomposes under gamma radiation and forms gummy deposits. The alcohols have been found to possess adequate radiation stability for this purpose but their low volatility is undesirable. It appears that calcium chloride brine (in mixtures of something like 25 percent by weight  $\text{CaCl}_2$ , 75 percent  $\text{H}_2\text{O}$ ) would be excellent for this purpose. If for any reason  $\text{CaCl}_2$  is found to be unsuitable, some other suitable inorganic antifreeze can undoubtedly be found.

The question of how to specify the maximum allowable fuel element temperatures has been in contention for years. When the AEC originally formulated a specification for protection against radiation in the shipment of irradiated fuel elements, it stated that the fuel elements should not, in the event of the loss of coolant, reach a temperature greater than  $180^{\circ}\text{F}$  below the melting point of the fuel element. This was a rather poor specification

because many of the fission products formed are gaseous and build up their concentrations within the element, as irradiation continues, exerting considerable internal pressure against the fuel element cladding structure. Almost all cladding materials will weaken significantly at a temperature only 180°F below their melting points and the gaseous fission product pressure integrated over the cladding surface may well result in a fuel element failure and a significant release of fission products. The present AEC standards, which are included in the container criteria, specify a margin of safety between the maximum temperatures the fuel elements may reach in the cask and the "failure temperature" where the failure temperature is to be determined from actual operating experience or from reliable experimental data.

The most desirable maximum temperature, specified in the criteria, would be the temperature at which the particular fuel element in question had been irradiated at for at least 30 days. This would undoubtedly be the maximum operating temperature and, with a proven fuel element type, this is an ideal specification.

On the other hand, if the fuel element has been tested to failure, a safety margin of 300°F below that failure temperature is given as maximum. Note the phrase "with due consideration for the irradiation and decay history of the fuel elements." This determination of failure temperature becomes a matter of scientific judgment. As mentioned, internal pressures build up within the fuel elements as irradiation progresses due to the continuous formation of gaseous fission products. The temperature at which a given fuel element will fail will then decrease as the irradiation of the fuel element continues or conversely, a new fuel should fail at a higher temperature than one with an extensive radiation history.

Paragraph 4.1.2.5 allows cask pressurization up to 50 pounds per square inch (gage) or 50 percent of design pressure, whichever is lower. This specification may seem out of place in a section on heat dissipation; actually it is not. Originally the AEC specified that casks designed for ground transport would not be pressurized but rather would operate at atmospheric pressure, for the sake of design simplicity. The Commission has decided, however, that the additional design complexity is justified by the increase in heat transfer efficiency and the fact that pressurizing the coolant decreases

the possibility of fission product leakage from a defective fuel element. Also, because of the precautions which must be taken to meet the pressurization specification the chance of coolant leakage from the cask, if the cask is somehow inverted or tipped, is decreased. As a result of this leaktightness specification, gases should be released from the cask only through the filter, required in the vent or pressure device (see paragraph 5.7 of the criteria). One of the big advantages cited for pressurized casks is that, where heat dissipation is a limiting factor in cask design, the pressurization of the cask enables the designer to ship more elements in a single cask, thus rendering the entire shipping operation more economical. Obviously, the big disadvantage is that, should the cask lose its pressurization, at least a part of the coolant may be expelled through evaporation. The specifications demand that no fission products be released even with total loss of coolant, however, and experience has proven that pressurized systems can be fabricated with a high degree of reliability. The advantages thus outweigh the disadvantages.

While not mandatory, it is highly recommended that a continuously reading pressure gage be incorporated into the design of the irradiated fuel element cask, if it is planned that the cask should operate at higher than atmospheric pressure. It is a must, of course, if the heat transfer characteristics of the loaded cask are to be checked by the "indirect" method discussed later in this section. The prominent presence and indicated reading of a Bourdon tube type of pressure gage will also be a tip-off to the reprocessing plant personnel that the cask is under pressure and should be carefully vented, although these personnel should already have this information.

A note here regarding the climatic extremes referenced in the criteria is in order. The reader may wonder why Mil Std 210 is frequently referenced and yet never quoted. This is done to prevent the criteria from becoming out of date as a result of any revision to Mil Std 210. The most current revision available at this writing is Mil Std 210A, dated 2 August 1957. It is completely possible that a new revision, a Mil Std 210B, may be forthcoming at some future date. For this reason the criteria reference Mil Std 210 rather than Mil Std 210A, with the inference that the latest revision is meant to apply.

As regards paragraph 4.5 which specifies that means must be provided, either directly or indirectly, for the measurement of the internal

cask wall temperature a thermocouple or a resistance thermometer may be used. A precalibrated milliammeter, millivoltmeter, a potentiometer (which is preferable) for the high temperature thermocouple, or wheatstone bridge type of instrument for the resistance thermometer, should be provided for use, with the cask. For this use, the resistance thermometer is preferable as it does not require a temperature reference junction, even though it will most certainly be the more expensive of the two types of sensors. Also, it will generally be the more accurate (usually  $\pm 0.25$  percent) of the two. This temperature measuring capability is required to perform the heat transfer analysis specified in paragraph 4.4 and to verify the thermal conditions existing in the inside of the cask after any unusual occurrence, as it is impractical to attempt a measurement of the fuel element surface temperature, which is the information that would actually be desired. Any penetration of the cask walls, which are made for the purpose of placing thermocouple junctions or resistance thermometer sensors on the inner-cask wall surface must be made so as not to violate any of the other sections of the container criteria (especially those on Radiation Shielding (section 3), Cask Pressurization (section 5), Structural Integrity (section 9), Vibration (section 10), Materials (section 13), Fire Survivability (section 14), and the environmental specs in sections 6, 7, and 8). These requirements probably make it more desirable to measure the inner-cask wall temperature by indirect means.

One such method involves calibrating the pressure rise in a sealed cask with a known void volume, initial pressure, and heat dissipation characteristics. By observing the pressure rise that occurs in the cask as a function of time after the initial pressurization (most probably at ambient pressure), one may, through a thermodynamic calculation, obtain a mean value for the coolant temperature. The pressure rise should, of course, stabilize out at the design operating value, given sufficient time, but points on the pressure vs. time curve can be used to estimate the interior cask temperature.

d. Cask pressurization and leakage

The specification is made in 10 CFR 72 that irradiated fuel element casks intended for ground transport should be capable of withstanding

an internal pressure of not less than 20 pounds per square inch (gage). For the purposes of air transport, this has been upped to a value of 30 pounds per square inch. As discussed previously, the failure of an aircraft pressurization and heating system will have little effect upon the low temperature specification for shipping containers. Such a failure will, however, subject the cask almost immediately, to the ambient pressure existing at the aircraft's altitude. Assuming transport in C-130, C-135, C-141 type aircraft, an altitude of 30,000 feet with an outside pressure of 4.48 psia (pounds per square inch, absolute) is representative. As normal atmospheric pressure is generally taken to be 14.7 psia a pressurization failure at 30,000 feet would then result in increasing the pressure drop across the cask walls and seals by approximately 10 pounds per square inch. This pressure has then been added to the AEC's minimum acceptable cask pressurization criteria (in paragraphs 5.1, 5.15, and 5.16).

Paragraph 5.2, which specifies the application of a seal to the lid closure so that the lid cannot be opened without the destruction of the seal is taken from 10 CFR 72. Its purpose is obviously to provide documentary proof that the cask has not been tampered with in a fashion which might cause unplanned biological exposures or loss of material, whether the shipment is to be under constant escort, or not.

As regards the containment of radioiodines mentioned in paragraph 5.8, the use of activated charcoal filters will probably prove to be the most satisfactory technique. They are often used for this purpose. There are several filters, commercially available, capable of capturing 99.9 percent of particulates greater than 0.3 micron in size whose efficiency is not appreciably affected by mechanical shock or atmospheric moisture. (Among these are the types "A", "E", and "H" glass fiber filters offered by the Gelman Instrument Company of Chelsea, Michigan. Other acceptable commercial filters are also available from the Millipore Filter Corp. of Bedford, Mass., and other suppliers.)

The AEC specifies that, if there is a possibility that explosive gases may be generated within the cask, preventive measures must be taken to preclude their ignition. The specification is reproduced in the proposed criteria (paragraph 5.9) not so much because such a possibility exists

as because it is desired that any packages designed for air transport also meet civilian, ground transport criteria. While there is a finite probability that hydrogen gas may be liberated from coolant water and collect, it is expected that the amount of such gas generated would be extremely small and the hazard would be negligible. If water is not the only constituent of the coolant (and there will probably be antifreeze added also, as previously discussed) any other agent which is to be added should be investigated as to its behaviour upon radiation at the integrated dose levels one may expect in the spent fuel element shipment in question. Some organics are extremely unstable under radiation conditions and may decompose into volatile gases. Fortunately, organic antifreezes have been ruled out for this application, by nature of their radiation decomposition properties, and are thus no worry. Any chemical suggested for such use should be investigated as to its radiation stability however; and if adequate data are not available on a likely candidate, an appropriate irradiation experiment should be conducted.

(e) Military climatic environments (temperature, humidity, blowing sand and dust)

The subject of the climatic extremes for which an irradiated fuel element cask should be designed is another matter of judgment. Unlike most of the other criteria proposed in this report, the cask designer should be allowed to make an application for waiver from any of these specifications if he can prove, using authoritative evidence, that the cask will not, under any possible usages, be subjected to these extremes of climate.

(f) Structural integrity

Section 9 of the container criteria discusses those specifications deemed necessary to ensure the structural integrity of an irradiated fuel element cask. The ability of the cask to contain the fuel elements and keep exterior radiation to reasonable levels under the adverse treatment it may receive as a result of routine handling or serious accidents is the prime consideration.

When shipping casks are subjected to rough handling or accident conditions the occurrence with the lowest threshold will undoubtedly be the loss of the cooling water. While it is reasonable to demand that the

cask not spill out its fuel elements in an unusual situation it would be farfetched to demand that water never leak out. As regards nuclear criticality, any spacing arrangements or attached materials designed to prevent possible criticality should retain their effectiveness up through the most violent possible accident, if at all possible.

An important point should be made here concerning the risks involved in air-transporting irradiated nuclear reactor fuel elements. In certain exercises of the nuclear safety analyses art, design criteria have been postulated and compliance with criteria demanded such that a package or nuclear system should be 100 percent safe even with the occurrence of "the maximum credible accident." This is taken, usually, to mean the maximum hypothetical accident or the worst postulatable accident. If one can prove his design can withstand the worst conceivable catastrophe without generating any hazards, so much the better of course, provided he has not paid an undue penalty for this capability. With the air transport of irradiated reactor fuel, it is not possible to achieve a package design capable of withstanding the "maximum credible accident."

For example, one may postulate a situation wherein a cask (such as the PM-1 cask) being flown to the reprocessing plant becomes involved in a mid-air collision between the plane carrying it and another aircraft. In such a situation the cask may well free-fall (unattached to any major aircraft debris) to the earth from an appreciable altitude. If the point of impact is at mean sea level and standard atmospheric conditions prevail, the PM-1 spent fuel cask would have a maximum terminal velocity upon impact of from 1,480 to 1,600 feet per second. (See appendix V for these calculations.) Contrast this with the fact that people in the field of cask design and testing are in some disagreement as to whether the maximum drop test for a cask should be from a height of 30 or 15 feet onto "solid" targets (this will be discussed further on). These heights correspond to maximum velocities of only 43.9 or 31.1 feet per second as opposed to free-fall terminal velocities of from 1,480 to 1,600 feet per second. (One might also consider the velocity upon impact of the cask in such an unfortunate instance as the collision of the transport aircraft with a stone mountain.) Obviously, then, one cannot realistically speak of designing casks to control the "maximum credible (or incredible if you wish) accident."

This is simply a fact of life which must be considered when evaluating whether this risk, involved in logistically supporting a remote nuclear power plant, is worth the benefits to be accrued from operating that plant.

It has been mentioned previously, in this chapter, that actual testing of a full-sized cask (especially for impact survival) is to be avoided wherever possible and that engineering analysis, judgment, or model testing approaches are more desirable because of the costs involved. In line with this philosophy the AEC in its most recent publication of 10 CFR 72 has specified an equivalent static load which may be substituted for the drop test specification. This force, which is to be 60 times the weight of the cask and its contents, applied anywhere on to the cask for a period of not less than 16 milliseconds, is taken to replace a 15-foot drop test specification. This force is predicated upon a 3-inch cask deformation. Although not specified by the AEC or in appendix V of this report, the force is taken to be a point load applied anywhere to the cask; the opposing support points must be so chosen as to represent the highest internal stress situation. The idea behind specifying an equivalent force for the drop test is, again, not to encourage the application of this force (or forces) to a cask in a test. Rather, this equivalent force is specified because it lends itself better to the engineering analysis approach.

The drop-test mechanical-impact specification, wherever it has been made, reflects concern on the part of the agency, ultimately responsible for the protection of the public from radiation hazards, about the consequences of a handling or collision accident, in transport. The impact speeds or release heights involved in air transport have never been considered in these specifications. The 23 September 1961 publication of 10 CFR 72 in fact states: "Shipment by air is not authorized by this part." The cask drop tests discussed and formulated in the past have primarily been meant to simulate accidents which might occur in handling during transport rather than the forces to be encountered in any very-low-probability, high-speed vehicular mishap. This should be borne in mind throughout the following discussion of drop testing.

The AEC's original formulation of 10 CFR 72 specified that irradiated fuel element casks must be able to withstand a 30-foot drop

onto a solid object with the assumption that the worst point of impact would be on a cover edge. Messenger and Fairbairn of the United Kingdom Atomic Energy Authority have been somewhat more specific in specifying that 1) the target shall be a rolled steel beam one foot wide and of length at least one foot greater than the width of the package and that it shall be rigidly mounted so as to have a maximum deflection of 0.01 inch under a 50-ton static loading placed at the center, and 2) that the drop shall be from a height of 30 feet for casks intended for general use, but only from 6 feet for casks with anchorage arrangements designed for  $12\frac{1}{2}$  g whose transport vehicle is specified in the approval. Neither the early 10 CFR 72 or the British test specifications offer an equivalent static load which may be applied to the cask in lieu of the drop tests. The British have measured in such drop tests decelerations approximating 2,000 g. The Canadian officials have issued a Board Circular No. 286 which calls for a 20-foot drop upon a target that deforms  $\frac{1}{2}$  inch. It has been noted that this usually results in decelerations on the order of 480 g's upon impact.

The AEC has retreated, however, to a 15-foot drop test specification, claiming that sufficient information is not available on the plastic deformation of the various materials used in cask construction and on the variation of the impact forces as a function of the angle of impact under dynamic loading conditions to design a cask in such a way as to predict with confidence that it would meet the 30-foot drop test. It also noted, in reviewing its original specification, that the meaning of the term "solid object" under such impact was uncertain. All of this led to the specification of the 60 times total cask and contents weight force for 16 milliseconds. As mentioned previously, it is unreasonable to demand that the cask retain its coolant under such circumstances and, in recognition of this, the Commission allows the external radiation level (one meter from the surface of the cask) to increase to a 1-roentgen-per-hour level.

This section on the impact survival of an irradiated fuel element cask is an appropriate place to make a point clear which has not been mentioned elsewhere in the available literature. It is highly desirable, in performing an actual irradiated fuel element shipment, that a small void space be left in each individually sealed internal fuel element compartment. As the casks will undoubtedly be loaded under water, in a spent fuel pit most likely,

this involves draining off a small amount of coolant from each individually sealed compartment. Paragraph 5.14 of the criteria in appendix III specifies that samples must be taken of the cask coolant 4 hours or more after the loading to determine the coolant activity. The taking of these samples and the adjustment of the level in the various internal chambers, to provide a small void space in each, could well be a combined operation. The reason for the desirability of these void spaces may not be obvious. If the internal cavities of the cask are completely filled with coolant, the application of any appreciable force to the cask will result in tremendous internal hydraulic pressures which could damage the cask and result in hazards far out of proportion to the applied force. The presence of small voids in each cavity will allow the coolant to expand into the gaseous cavity, resulting in much lower internal pressurization. The inclusion of these small void spaces is desirable in spite of the specification in paragraph 5.6 specifying a pressure relief valve which will open at 75 percent of the design pressure, for "pressurized" casks (meaning those operating under a pressure as stated in paragraph 4.1.2.5 to enhance their heat transfer characteristics). First, the inclusion of a relief valve is not specified for packages which are normally designed to operate at atmospheric pressure. Second, even if the relief valve opens upon a severe shock to the package (assuming it has one), the spilling of coolant to the surroundings is highly undesirable, especially if measures can be taken which will preclude undue pressurization of the cask without ejecting any coolant into the surroundings. Third, the relief valve may not be adequate to prevent plastic deformation and partial failure of the cask because of either too slow a response time or too small a relief orifice. Aside from the problem of tremendous cask pressurization upon severe mechanical loading it should also be pointed out that with a "solid" coolant system (completely full of liquid) even small temperature variations can result in very high internal cask pressures, resulting at least in leakage if not mechanical damage. One precaution should be taken in the leaving of a void space. If possible, no portion of any fuel element should extend into the void as the heat transfer process will be thus impaired. A proper cask design should provide for adequate voids and yet preclude exposing any portion of any fuel element to the gas in the voids whether the cask is upright or standing on its lid.

An interesting sidelight concerning drop tests is furnished by the British who have stated that a 19-foot drop test onto concrete satisfactorily simulated a parachute drop. As the ejection of irradiated fuel casks from an aircraft, in an emergency situation, is discussed later, this is particularly interesting test specification. (Though not directly pertinent to this study, it is also interesting to note that the United Kingdom Atomic Energy Authority regards a 40-foot drop onto a steel plate wet-floated onto concrete 18 inches thick as a suitable test to simulate shore-to-ship handling. This is what they must undoubtedly regard as the maximum height from which a package might be dropped from a crane hook or cargo net.)

It should be emphasized throughout this discussion of the drop testing of irradiated fuel element casks, that credit may be taken for the protection afforded the cask by any crash shield or crash frame for a single impact, provided, of course, there is no chance that the impact might strip the frame or shield from around the cask. It is assumed that any following mechanical forces applied to the cask after the impact will be of lesser magnitude and so the protection subsequently afforded the cask by the crash frame or shield is usually not considered in any analytical evaluation of the cask design.

A most important point is raised in paragraph 9.4 of the criteria. This is the structural integrity specification which corresponds to the specifications in section 2, Nucleonics. Not only is it necessary to preserve geometry if such is required to meet the nucleonics criteria, but should any materials have to be added to the core or cask to meet the criteria (i. e., neutron poisons), they also must remain in place upon the application of the forces described in section 9. This should not constitute much of a problem provided the lid remains on the cask.

The specification for resistance to foreign object penetration is new for the AEC. The fact that the specification is slanted toward cladding the outer shell with steel plate is a result of 1) the poor mechanical properties of most efficient shielding materials, particularly lead, and 2) the low melting point of the most popular shielding material, lead, and its inability to meet the fire survivability criteria in section 14 without encapsulation in a relatively high-melting-point material, usually steel. It is hoped that this specification will preclude the severe damage to an all-lead cask which could result upon

impact with a solid object involving the absorption of a rather small amount of kinetic energy.

It should be noted that the allowable stress specified as that which should not be exceeded in the drop test or equivalent is the tensile strength rather than the yield limit. The tensile strength may be crudely defined to be that point above which mechanical failure in the form of fracture occurs, while the yield limit may be taken to be that maximum stress at which, upon the removal the load, the member springs back to its original dimensions, retaining its other original mechanical properties. The yield limits for lead at room temperature are of the order of a few hundred pounds per square inch while the tensile strength (for cast lead) may run as high as 7,000 pounds per square inch. In contrast, mild steel has a yield point in the neighborhood of 64,000 pounds per square inch and a tensile strength of 75,000 pounds per square inch. The important point here is that deformation is allowed upon the application of the forces listed in section 9 (indeed, with lead it is unavoidable). The philosophy which must be adopted if one is to be realistic is that the resultant deformation must not result in an unacceptable compromise of the basic principles of the packaging of irradiated fuel elements (i. e., prevention of release of contents, limiting of external radiation levels, dissipation of heat generated by the contents of the package, and the prevention of criticality).

In summary, it is reiterated that the maximum postulatable accident is an unfortunate, though improbable, occurrence which simply cannot be designed for, due to limitations of cost and materials technology. The drop test criteria are meant to ensure that safety violations as a result of packaging inadequacies do not result in handling mishaps; they are not to be construed as automatically adequate for an air transport catastrophe. It should be mentioned here that the picture is not as black as one might have been led to believe so far. The casks, by nature of their massive walls, are tremendously strong packages; certainly they are stronger than any other cargo of comparable dimensions an airplane might carry. While determining the failure point of such a cask is a most difficult task, Poindexter<sup>13</sup> has estimated that the SM-1 cask shown in figure 10 can withstand a side-on load of at least 90 g's before exceeding the short-time yield stress of the lead side walls. While little data

exists on g loadings in aircraft crashes, when one considers all the shock mitigating material which surrounds the package (namely the aircraft structure) and the probability that an impact would be into soft earth, water or through a good deal of yielding flora, it is reasonable to assume that acceleration values greater than 90 g's would rarely be seen, even in severe air crashes. Of course, there is always the minute possibility that a C-141-type aircraft traveling at 550 knots, will collide with the perpendicular face of a granite mountain, but the risk of electrocution that the average citizen takes in the routine use of electricity in his home is undoubtedly orders of magnitude higher in probability than that of such an occurrence.

The prime consideration in the criteria dealing with mechanical integrity has been then to ensure compliance with standards established for the routine, ground transport of such items so that those channels may be used by the military if desired.

(g) Vibration

The effects of vibration on packages are often neglected. A structure capable of surviving a severe accident may fail during transport because of the prolonged vibration of some component or assembly, especially at its natural frequency. During long journeys this vibration may loosen fastenings, produce fatigue failure or cause sharp projections to "nibble" their way through other materials.

The AEC specification concerning vibration says only that "The cask shall be capable of withstanding vibration incident to shipment without impairing the integrity of the closure or of the cask itself." While this is good general guidance, the author of this report thought that it did not offer the specific guidance required by an agency evaluating a cask design for possible air shipment. The frequencies given in section 10 of the criteria in appendix III are taken from British data<sup>17</sup> which have been compiled primarily for piston-engine rather than jet or turbo-prop aircraft. (The vibration problem in piston-engine aircraft is normally taken to be much greater than that encountered in jet and turbo-prop aircraft, except perhaps in "bumpy" weather.)

The envelopes of frequencies and amplitudes specified in paragraph 10 are applicable for all fixed-wing air transport. They are not

meant to apply to transport in rotary-wing aircraft. If shipment is planned in rotary-wing aircraft, the particular vibration spectrum extant in the cargo hold should be determined and made to apply.

In cargo planes the holds are mainly in the central region. Vibration is generally between 10 and 500 cycles per second with an amplitude of  $\pm 0.008$  in. at the lower frequencies. The amplitude at higher frequencies is about  $\pm 0.001$  in., but this applies to built-in structures rather than to freight. The envelope of vibration amplitudes in all directions at selected frequencies is given in the table in paragraph 10 of the criteria. In pure jet aircraft, the afterhold may lie within the extension of the power unit region arising from the jet. In this region there is acoustic vibration (with a maximum in the transverse axis) in the range of 100 to 1000 cycles per second and exposed equipment might experience accelerations up to 80 g's corresponding to  $\pm 0.001$  in. at maximum frequency, but this again is unlikely to affect packages inside the aircraft. Most likely, the lower frequencies are the more harmful.

It again should be noted here that it is not the intent of paragraph 10 to demand that every newly designed cask be subjected to a test program which exposes a cask to all the frequencies and corresponding amplitudes given. In fact one might very well ask where a shake table capable of such testing of a 30,000-pound cask could be found. Rather, it is the intent of this specification to bring to the attention of the cask designer the fact that his cask must endure these frequencies for long periods of time. He should take whatever precautions are necessary to ensure that fastenings and valves do not vibrate open and that abrasive action between fuel elements and the cask interior will not occur. He should also determine that none of the structural members or components of the cask have natural frequencies or low-order harmonics in the regions listed in section 10 of the criteria. The cask designer may prove compliance to the approval agency through engineering analysis. Again, a test program should be entered into only as a last result, provided it is even possible.

(h) Weight, size, and floor pressure in aircraft

The irradiated fuel element cask package must be compatible with the aircraft for which it is intended. Section 11 of the Container Criteria

specifies the references which provide sufficient information to ensure this compatibility. The major areas in which compatibility must be proved are payload carrying ability, aircraft floor pressure specifications, and dimensional maximums.

Performance characteristics for USAF aircraft are given in the Air Force "dash 1" technical orders. For example, the appropriate reference for the C-130A aircraft would be T.O. 1C-130A-1. It is probable that any planned airlift shipments of reactor materials made in the foreseeable future will be formulated for rather specific missions. The maximum distance for the different air-lift legs of the transport operation will undoubtedly be specified by the plant siting. This will constitute a restraint upon the weight of the irradiated fuel cask, contents, pallet, and tie-downs. The value of this maximum weight will be derived from the dash 1 technical order.

The matter of floor loadings is very critical for military aircraft. Exceeding established floor loading limits may result in straining the aircraft structure, generating not only a significant hazard if the strain is undetected or generated in flight (say, as a result of buffeting in turbulent air) but a significant cost to the government in the restoration of the aircraft to a satisfactory condition. Floor loading limits, in terms of pounds per square inch, pounds per linear foot, and wheel or axle static and in-flight loads, are given in the aircraft "dash 9" technical order (as for example, with the C-130A, T.O. 1C-130A-9). These limits should not be exceeded either in the loading operation or upon tie-down. One finds, usually, that the load limits established for bulk cargo are generally lower at the aft and ramp portions of the plane than in the central section which might lead to the question of how to load the plane, over these sections, to reach those having the higher allowable floor loading. Fortunately, these aircraft are furnished with treadways, over which the package can be rolled or skidded for loading and unloading. These treadways are rated at much higher loads than the whole floor of the aircraft. The C-130A, for example, can support only 1,000 pounds per square foot of bulk loading in the aft end but the treadways in this section can support 6,500 pounds per wheel or 6,000 pounds per axle during takeoff, flight, and landing. Tires which will exert a pressure greater than 50 pounds per square inch will require shoring, however. The dash 9 technical order also contains the locations and

ratings of the tie-down fittings in the individual aircraft, which is essential information for the design of a tie-down scheme. There are three kinds of tie-down fittings provided in the C-130A; they are rated at 5,000, 10,000, and 25,000 pounds. The 25,000-pound tie-down fittings can be used for the attachment of snatch blocks. These snatch blocks can then be used to guide cables when these are used to pull cargo up the ramp and into position on the cargo floor. The motive power for such an operation can come from a truck or tractor outside the plane. The portable electric winch provided for use with the C-130A (for example), may not be powerful enough to pull the irradiated fuel element cask and pallet up the ramp, but could be used to position the cask accurately upon the cargo compartment floor. A pallet for use with such a load in an aircraft such as the C-130A will probably have skids which must be greased (with something like Alvania EP-2 grease, or equivalent) so that the treadway load limits will not be exceeded in loading or storing the package. In pulling the cask over some portions of the aircraft's floor, shoring may be required to keep within acceptable load limits. If load limits can be met with a wheeled pallet, the wheels should be jack-actuated so as to retract when the load is in proper position in the cargo hold unless the load imposed on the treadways by the wheels do not exceed those allowable values for take-off, flight, and landing conditions. If wheels are not to be retracted, they must be adequately braked.

If the irradiated fuel element container is to be rigged so as to be ejected from the aircraft and parachuted to earth in the event of certain mid-air emergencies, other provisions will have to be made for loading. With either conventional or 463L (to be discussed later) equipment, ejecting cargo from the aircraft calls for the installation of rollers on the cargo hold floors; loading and unloading operations would make use of this equipment and would be limited by its load-bearing capability.

The determination of the dimensional suitability of a package to a specific aircraft should be made from the dash 9 technical order for the specific aircraft or U. S. Air Force Specification Bulletin 518, "Cargo, Aircraft Equipment, Dimensional Data." This bulletin provides tables specifying the maximum size of packages that may be accepted through the different door openings of common Air Force cargo aircraft.

Copies of U. S. Air Force Specification Bulletin 518, Mil Std 210A, Mil-A-8865, Mil Spec 33586 and any other service bulletins, specifications, or standards can be obtained by an Air Force contractor through his local Air Procurement District office, who in turn will obtain copies of them from the Naval Supply Depot, 5801 Tabor Avenue, Philadelphia, Pennsylvania.

Wherever possible, cask pallets should be made compatible with the newly developed 463L Materials Handling System. Briefly, this system is an attempt on the part of the Air Force to bring the ground handling of materials in phase with the high-speed, large-payload aircraft entering the Air Force inventory. This system will replace the outdated forklift and manual system or cargo handling with the concept of "palletization." The system consists of five families of equipment: 1) air-transportable terminals for airhead operations, conveyORIZED to provide sorting capabilities or automated, consisting of conveyors, power, and automatic sorting for high traffic flow; 2) cargo preparation equipment consisting of pallets, restraining nets, and consolidation containers designed to increase the speed and efficiency of cargo preparation; 3) a variety of self-propelled adjustable height loaders, trailers and modified forklifts designed for the rapid loading and off-loading of cargo aircraft; 4) label printers and data integrators to control the air cargo flow from source to user; and 5) sets of rails, rollers and locks which attach to the floor of cargo aircraft and provide for rapid loading, off-loading, and restraining of pallets.

The 463L system is not yet widely operational within MATS or any other command and a shipping agency might have some difficulty obtaining an aircraft so equipped. It is planned, however, for MATS at least, that all C-130's, C-133's, C-135's and C-141's will be equipped with the 463L system sometime in the future.

Details as to equipment design and compatibility can be obtained from the Air Force Aeronautical Systems Division (Attn: ASZL), 463L Systems Project Office at Wright-Patterson AFB, Ohio.

(1) Pick-up points and tie-down fittings

It is obvious that every cask designed to be used by the Air Force in the air transport of irradiated reactor fuel, must be compatible with

the equipment of the reprocessing facility for which it is destined. In the past, only the Idaho Chemical Processing Plant reprocessed stainless-steel fuel elements. There is now a possibility that the stainless-steel-clad fuel elements containing enriched uranium will be processed at the Savannah River Plant (Aiken, South Carolina) instead. A determination of which plant is to reprocess the reactor fuel elements in question must be made before a cask design can be accomplished since the compatibility requirements vary with the two installations, as one may see by examining subappendixes 2 and 3 of appendix III. While the criteria in these subappendixes are current as of the writing of this report, they may change with time; so any agency planning to sponsor a cask design should check with the USAEC Operations Office administering the reprocessing facility to ensure that these criteria are complete and up-to-date. With reference to the Idaho Chemical Reprocessing Plant, one should contact the Chief, Chemical Processing and Development Branch, Idaho Operations Office, United States Atomic Energy Commission, P.O. Box 2108, Idaho Falls, Idaho 83401. The appropriate contact for the Savannah River Plant is the Chief, Chemical Process Branch, Technical and Production Division, Savannah River Operations Office, United States Atomic Energy Commission, P.O. Box A, Aiken, South Carolina 29802.

A review of the acceptance criteria in subappendixes 1, 2, and 3 reveals that they are, for the most part, restatements of 10 CFR 72 with provisions added to ensure compatibility of cask designs with reprocessing plant equipment. As the proposed criteria of appendix III exceed 10 CFR 72 in certain areas and retain at the least the minimum AEC specifications in all others, casks designed to the specifications of appendix III should encounter no trouble in satisfying the general acceptance criteria of the reprocessing plant.

If the irradiated-fuel package is to be capable of being ejected from the aircraft in the event of an in-flight emergency, particular pallet design and tie-down criteria must be met. General requirements for jettisonable cargo equipment design are given in the dash 9 technical order for the aircraft in question. Details concerning pallet design, parachutes, and ejection mechanisms can be obtained from the organizations listed in this section.

Other provisions of section 12 of the proposed criteria (paragraphs 12.2 - 12.5) are based upon AEC experience and common sense and will not be discussed in detail here.

(j) Materials

Paragraph 3.4 of the criteria specifies that uranium and any other substance having a melting point lower than 1000°F shall be completely encased in welded mild steel or other material having a melting point higher than 1000°F. This is aimed primarily at ensuring that lead and uranium are so encapsulated. For lead, this need is fairly obvious. It melts (in pure form) at 621°F and gives off toxic fumes in addition to generating the hazard involved in the loss of shielding. The need to encapsulate uranium may not be too obvious. One finds that uranium has a very high melting point, approximately 4,350°F. Uranium, however, happens to be a pyrophoric metal similar to zirconium, magnesium, and titanium. Large pieces normally do not burn without the continued application of external heat. However, chips, turnings, and fines ignite easily (sometimes spontaneously) and burn with an intense heat.<sup>18</sup> One is then concerned, here, with the possibility that small pieces might be scraped or dislodged from the surface of an unencapsulated, uranium metal cask and ignite, causing a fire. To a lesser extent, one might be concerned about the entire uranium cask structure igniting when exposed to a heat source as great as a severe petroleum fire. The other undesirable aspect of an unencapsulated depleted uranium cask concerns surface contamination. U<sup>238</sup> (depleted uranium) is continually emitting alpha particles (of approximately 4.2 Mev) and, if unencapsulated, represents a continual contamination problem. While the contamination levels registered as a result of a smear test will vary as a function of the uranium metal surface finish, it is safe to say one will find that health-physics allowable radiation-contamination levels (such as those in paragraph 15.2 of the criteria) will be exceeded anytime one makes the test. It is for these reasons that the encapsulation of uranium is deemed necessary.

One sentence in paragraph 13.4 states that "a provision shall be made for assuring, by deformation of the container walls or controlled voids in the shell or similar means, that the welded shell will not rupture if the cask

is exposed to the standard one hour fire, etc." Lead has a higher volumetric coefficient of thermal expansion (approximately  $4.71 \times 10^{-5} (^{\circ}\text{F})^{-1}$ ) than those of the metals which will usually be chosen to encapsulate it (mild steel has a volumetric coefficient of thermal expansion of approximately  $2.50 \times 10^{-5} (^{\circ}\text{F})^{-1}$ , or a little more than half that of lead). In considering the mechanical integrity of the cask upon subjection to temperatures such as those encountered in petroleum fires one must be sure, then, that the lead has room within the cavity formed by the external material, to expand without bursting the outer shell and that, in expanding, it will not overstress the exterior metal as a result of any interface bonding. The latter is not much of a bother, first, because in most casks which have to be disassembled and inspected, it has been found that no bond is made between the lead, on the inside and the exterior material (in these cases, steel)<sup>14</sup> and, secondly, because if such a bond is made, failure will occur first in the lead because of its much lower shear strength. As regards the problem of compensating for the differences in expansion of the materials upon the application of heat, the only acceptable method is to leave a controlled void inside the cask wall shell. This void should be of sufficient volume to allow the lead (either in solid or liquid phase) to expand or flow into it without additionally stressing the outer material.

Two very important points of caution should be made, regarding these controlled voids in cask wall shells. First, they must not be positioned under normal circumstances so as to result in a violation of the shielding specifications given in section 3 of the proposed criteria; i. e., the criteria of "200 milliroentgens per hour at any accessible surface and 10 milliroentgens per hour at a distance of 3 meters from the surface," must not be violated as a result of the inclusion of this void in the cask wall. The second important point is that the void must be completely free of any substance in the solid or liquid phase which will vaporize at a temperature lower than  $1,700^{\circ}\text{F}$ . Should any such substance be present, the vaporization, when it occurs upon the application of sufficient heat, will result in a tremendous pressurization of the internal shell which would probably lead to an explosive cask failure. This failure has been noted with water, the most common such culprit, by Underwriters' Laboratories, Inc., in the explosion of a simulated large self-shielded shipping container at temperatures in the vicinity of  $1,460^{\circ}\text{F}$ .<sup>14</sup>

Also, Oak Ridge has noted the presence of approximately 500 milliliters of water in each of three casks its personnel disassembled and examined, indicating that they might fail in similar fashion upon fire simulation testing. It is then imperative that air filling these controlled voids in cask walls be completely dry and clean. This will undoubtedly cause manufacturing problems, most probably in the performance of the final weld seal on the encapsulating outer shell, and additional cost, but such precautions must be taken if the fire-simulation test specification is to have any meaning.

It seems that problems arising from the corrosion between galvanically dissimilar metals have been overlooked. The AEC specification merely states that there shall be "no significant chemical, galvanic, or other reaction between them (materials of which the cask is constructed) or with fuel elements." The author of this report did not believe this statement was explicit enough and so has included reference to Mil Spec 33586, "Metals, Definition of Dissimilar," to define just which materials may or may not be brought into intimate contact with one another. It is interesting to note that, under this military specification, certain previously fabricated and AEC-approved casks are unsatisfactory. (The PM-1 cask, shown in figure 1, for example, has lead and stainless steel in intimate contact. Lead is a Group III material while stainless steel is a Group IV material, according to MS 33586, and they are dissimilar. It is also interesting to note that no accommodation for a void is made in the PM-1 cask design, as discussed in the preceding paragraph. Yet, this design was approved by the AEC, Division of Licensing and Regulation, subsequent to the publication of the current 10 CFR 72, in September 1961.) If lead and stainless steel (two very common metals) are to be used in the same cask, they must be appropriately masked. If they are only to be in contact at the inner surfaces of the wall cavity and one can be absolutely positive that no moisture will be present in the cavity (including its void), then there is no worry; galvanic corrosion does not occur between dry surfaces as no ion exchange process is possible. Of course, then, it must be definitely proved that no water will ever leak into the interior of the cask wall; it should be remembered that these casks spend a good deal of their lives under water, at depths of tens of feet and that low-velocity impacts may easily violate the outer shell of the cask - because of the cask's tremendous

inertia. With these considerations in mind, it is better to conclude that dissimilar metals should never be used in a cask design except where they can be positively isolated by bushings, washers, heavy plating, painting, or the like.

One last item to be mentioned concerning the possible galvanic interaction between cask materials is that this author was unable to readily find any information on the galvanic properties of uranium metal. If such is considered for use as wall shielding material, its properties as regards possible galvanic corrosion between it and other cask materials, should be determined.

Regarding the specification of tie-down strengths in paragraph 12.3 of the proposed criteria, the tie-down fittings have been specified to conform with Mil-A-8865, "Military Specification, Air Transportability Requirements, Ground Support Equipment, General Specification for," paragraph 3.2.3 quoted below.

Miscellaneous equipment (USAF only) - For cargo engines, fuel tanks, turrets, and other large items of equipment other than serial delivery equipment, the following minimum load factors acting separately shall apply:

Longitudinal	8.0 (g) forward, 1.5 aft
Lateral	1.5 (g) right and to left
Vertical	4.5 (g) down 2.0 (g) up

As the limits specified in Mil-A-8865 are greater (with one exception) than those given in 10 CFR 72, the former are largely taken to supersede the latter. 10 CFR 72 merely specifies a vertical load capability, up or down of 2 g's, but specifies a horizontal load of 10 g's. The 10-g fore and aft load capability sub-spec from 10 CFR 72 was retained as it was higher than the Air Force's 8 g's forward and 1.5 g's aft and is thus more conservative.

The maximum credible accident usually postulated for a loaded, irradiated fuel element container is a severe impact followed by a petroleum fire and, then, possible immersion in water. Mechanical accidents involving fissile materials are commonly supposed to increase the risk of a

criticality accident. In fact, the opposite is generally more likely, since most accidents are dispersive in nature, whereas criticality requires that an assembly be made.

(k) Survivability in fire

The question of what constitutes a suitable, realistic fire-simulation test is another one of interpretation. Temperatures have been recorded in the hottest portions of petroleum fires, started under ideal conditions, that exceed the melting point of steel. However, aircraft fires usually occur under far from ideal conditions and when one is speaking of the heat input to an object with as much thermal mass as an irradiated fuel element cask, one should realize that the subjection of a cask to a very high temperature for a short period of time will not result in an appreciable temperature rise in the inside of the cask because of the low transient heat transfer rate.

The fire test cited in the proposed criteria (appendix III) is that of 10 CFR 72, chosen because of the desirability of conforming with civilian standards, as discussed previously. The "standard one hour fire" as defined by the National Fire Protection Association and the American Society for Testing Materials calls for a gradual rise in the temperature of the environment surrounding the package with the curve passing through the following points: 1,000°F after 5 minutes, 1,300°F after 10 minutes, 1,550°F after 30 minutes, and 1,700°F at the end of the hour. These specifications then call for the rapid cooling of the package such as that achieved by spraying it with fire hoses.

The British believe they have established a more rigorous fire test and they are probably right. The United Kingdom Atomic Energy Authority immediately exposes the package to 800°C (1,472°F) and holds the temperature constant for 30 minutes. At the end of this period of time the package is taken out of the oven and allowed to cool naturally; no artificial cooling mechanisms are allowed. Even though the British test calls for a lower integrated heat input into the package than the American test, it is regarded as more severe primarily because of the specification forbidding artificial cooling (in fact, in UKAEA tests, maximum internal temperatures have been obtained during the cooling period) and because the immediate

subjection of the package to 800°C temperature is more conducive to damage by thermal shocking. The point here, as before, is not to require actual testing of packages, which would be very complicated and expensive, but rather to assess the ability of the packages to meet the criteria by engineering evaluation.

An interesting sidelight concerning the hardware state of the art to meet those portions of the criteria proposed in this section, which is based upon 10 CFR 72, concerns gaskets. To date only one gasket material has been found which seems to be capable of withstanding the pressurization specifications (paragraphs 4.1.2.5 and 5.16) and the fire test specification (paragraphs 14.1 and 14.2). This material, reported on by Mr. K. N. Haff of Oak Ridge National Laboratory, is Taylaron PA6, manufactured by the Taylor Fibre Company. At the last reporting,<sup>14</sup> though, Oak Ridge was also considering fabricating and testing containers using metal gasket seals of materials such as Conoseal, manufactured by Marman Division of the Aeroquip Corporation.

(1) Ruptured fuel elements

Fuel elements in reactor cores have occasionally been known to fail. Most fuel elements (be they in flat plate or tubular geometry) are made in sandwiches in which stainless steel or aluminum are the "bread" with the fissionable material, in some stabilized chemical and physical form, being the "meat." Large internal pressures are generated within the "meat" due to the buildup of gaseous fission products. The heat generated by the fission processes increases this internal gas pressure, and also reduces the mechanical strength of the cladding material, sometime (though seldom) to the point where the gas pressure causes a break or rupture in the cladding. Boiling and cavitation occur on the surface of the exposed meat causing solid chunks of "meat" containing fission fragments and fuel material to migrate into the primary coolant free stream. The release of fission fragments and nuclear fuel material to the primary coolant stream (speaking now of pressurized water reactor systems, which undoubtedly will be the most common military reactor type for years to come) constitutes a highly undesirable contamination problem. All plants have maximum allowable contamination limits for their primary coolant, though some may differ from others. When these limits are exceeded

the operation of the reactor with the failed fuel element present in the core is no longer tolerable and the element, or smallest subassembly containing the failed element, must be removed and shipped to a special facility capable of handling the failed fuel material and (probably) analyzing the failure.

AEC standards (reproduced in paragraph 15.1 of the proposed criteria) call for the encapsulation of the failed fuel element or fuel element subassembly in a container, within the cask. This is necessary to prevent cask coolant contamination from exceeding the levels specified in paragraph 5.14 of appendix III. The material of construction of the container must be compatible with the chemical process, on the basic assumption that the entire capsule will be charged to the dissolvers in the chemical reprocessing plant.

Usually the same cask that is used for shipping irradiated fuel from the plant will be adapted to shipping the failed, irradiated fuel as shown for the PM-1, in figure 13. Then other core segments or elements will probably not be included in the shipment. This is because the destination may well be different, because encapsulation of the failed portion of the core will impair the heat transfer capability of the irradiated fuel element cask if one is speaking of the full, normal loading, and because the envelope in which the failed portion of the core will be placed will undoubtedly take up much of the room that would normally be occupied by other irradiated fuel elements.

It is most important, in designing the envelope for the failed, irradiated fuel element, that the heat transfer and pressure buildup phenomena to be expected, are thoroughly analyzed, bearing in mind that the element must be completely sealed off from the surrounding environment. Provisions made internal to the envelope should be adequate to satisfactorily contain any pressure buildup and transfer heat, in keeping with the rest of the criteria for shipping spent fuel (and particularly with section 4, Heat Dissipation).

If, within the reactor core, the failed fuel element or core subassembly cannot be located, it may be necessary to ship the entire core to a facility with a capability to identify the culprit and make corrective repairs. In this case, the military sponsoring agency may take the responsibility for making a shipment which conforms to the every item of the criteria except paragraph 5.14 which specifies maximum cask coolant activity levels under normal operation.

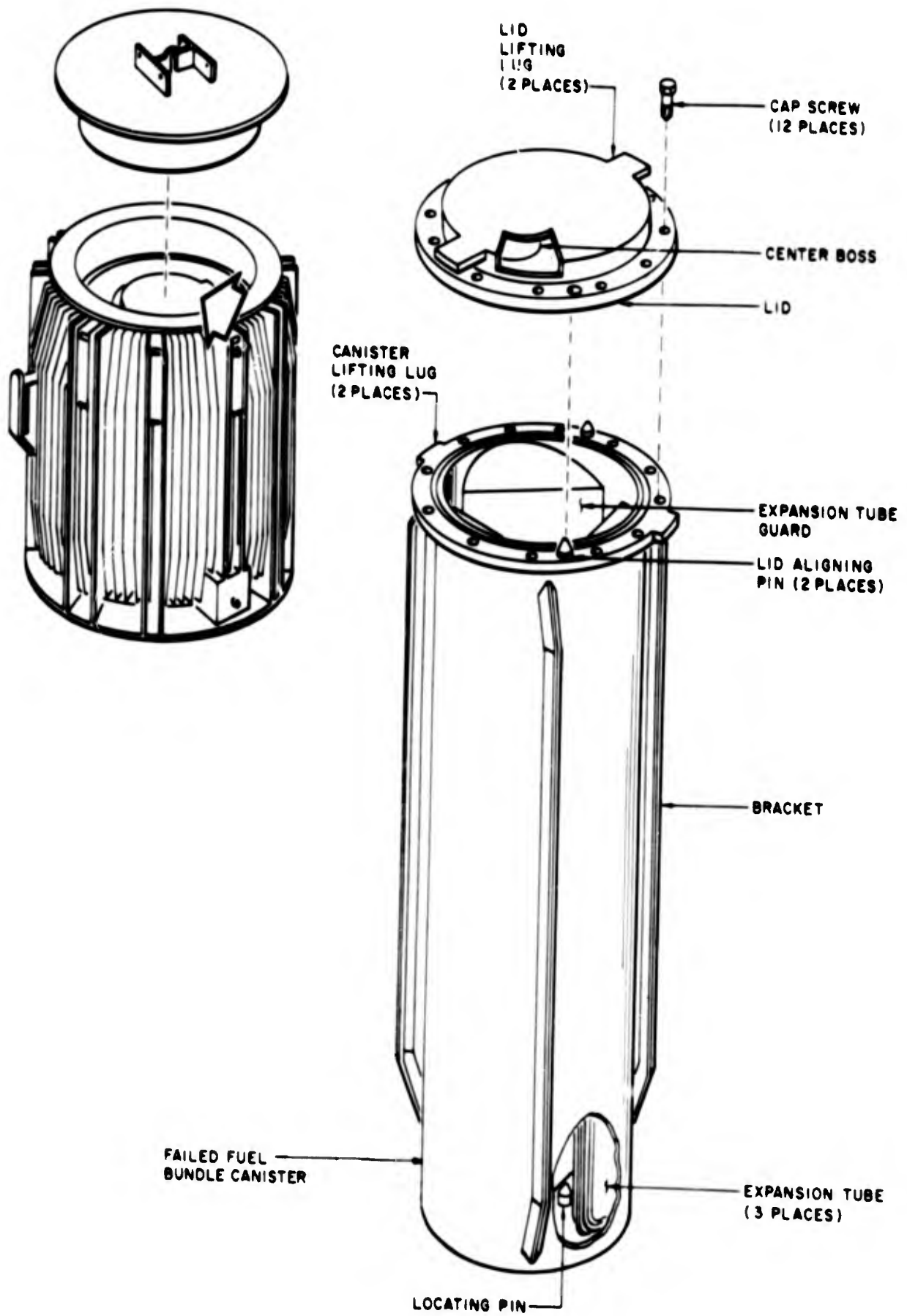


Figure 13. Failed fuel bundle canister

Except for plants using well-proven fuel elements, the developmental planning of any new military nuclear power plant system should include a design and appropriate analysis for a failed fuel element container within its design and engineering analysis of the irradiated fuel element cask.

Any preliminary design of a container for failed fuel must be coordinated with the reprocessing plant to which shipment would be made, to ensure compatibility. Present ICPP standards, for example, allow only 4½ inches for the maximum acceptable diameter of a damaged fuel container and 40 inches for the maximum container length. As might be expected, they also specify that no inert gasketing materials should be used in the design and that 50 to 100 grams of steel wool (not stainless steel) be packed around the fuel element to "trigger" the dissolution reaction.

(2) New reactor fuel

It is anticipated that the only type of fuel elements which might be presented for shipment in the foreseeable future will be those containing what is known as "fully enriched uranium." This is uranium which is approximately 93.5 percent enriched in the isotope  $U^{235}$ , by means of the gaseous diffusion concentration process. These fuel elements, as they are shipped to the reactor site, are only very slightly radioactive. This level of radiation, so low that no biological shielding is required, is due to the natural decay of the uranium. Also, the fuel elements are relatively uncontaminated, as they have been very carefully cleaned, in all cases. The amount of contamination remaining is usually less than the background radiation of the atmosphere, and it therefore constitutes no hazard to persons handling or transporting the fuel elements.

While most new reactor cores are tested in zero-power, wet critical facilities to determine initial core reactivity, rod response, and rod worth, they are not operated at any finite power level and the fission product buildup is negligible. This and the radioactive decay of the fuel material are not sufficient to produce any detectable amount of heat.

(a) Nucleonics

The major and almost sole consideration in the shipment of

new fuel elements is, then, the prevention of criticality. This almost completely dictates the packaging design philosophy.

Low-power reactor cores of early design and today's high-power (above say, 50 Mwe) cores usually consist of a number of fuel plate or fuel tube bundles, each of which may be handled separately and shifted into different positions, within the core, relative to each other. Obviously, a core designed in such a fashion, lends itself well to the easiest approach to the criticality problem, namely the shipping of a core in parts. Unfortunately, the trend in low-power (1-10 Mwe) reactors which are typical of the kind which would be sited at a remote location, seems to be towards cores of a more integral design in which a significant portion or all of the fuel rods are firmly attached to each other through a solid core structure. Such is the case with the PM-1 and PM-3A reactor cores, which divide only into sixths and which are designed to be shipped in toto. Because of this design, these cores are also shipped with the neutron absorber control rods in place to "hold down" the reactivity of the assembly.

While fuel elements and new cores are usually shipped dry from the manufacturer's test or inspection facility, it is always assumed that the shipping cannister is not only full of water but also surrounded by water as this is a more reactive configuration and corresponds to the accident in which a cannister seal is breached by impact and then the package is submerged in water. As with irradiated fuel element casks, while it is demanded that the cask contain its charge, it is thought unrealistic to expect the cask to maintain its barrier to water penetration.

(b) AEC standard

It is also desirable, here, that standards established by the U. S. Atomic Energy Commission and the International Atomic Energy Agency (if applicable) for the shipment of such fissionable or fissile material (the two words meaning the same) be adhered to. These standards, while binding upon only USAEC licensees in this country and not necessarily on the Department of Defense, are based on a good deal of experience in this field.

The USAEC sometimes also refers to fissionable or fissile material as "special nuclear material" and publishes the regulations it holds

as binding upon its licensees, regarding assembly and transport of such material as parts 70 and 71 of Title 10 of the Code of Federal Regulations (10 CFR 70 and 10 CFR 71).

The USAEC classifies packages of special nuclear material according to the shipping procedures which must be imposed upon the package or the shipment (10 CFR 71). Class I may be said to include packages which are safe from neutron interaction in any arrangement, even after a very serious accident. Items falling in this class include very dilute aqueous solutions of fissionable isotopes.

Class II packages are limited as to content so that the individual unit is safe from accidental criticality, and the number of such packages, which can be transported together, is limited so that shipment of the allowable number is safe. Class II packages may be transported by any carrier. The number of packages which may be carried on the same vehicle with other shipments and placed together on a loading dock or storage area is limited by the assignment of a certain number of "units" to each package. The allowable number of class II packages which may be safely accumulated in one area in any arrangement includes a safety factor of at least 5. The number of packages limitation for class II shipments is stated in terms of "units." 10 CFR 70 limits the number of units that may be assembled at any one location to 40.

The definition of a unit, which is very complex, may be found in 10 CFR 70. The specification is made in terms of mass and geometry criteria but also related to the degree of moderation control, with allowance factors for varying low U-235 enrichments, for cylinder shapes, and the density reduction resulting from the dilution of U-233, U-235, Pu 239 by other elements. A unit is a rather small fraction of a critical mass as may be seen from the following example: One unit of uranium, enriched in the fissionable isotope  $U^{235}$  to only 5 percent, may not exceed 0.6 kilogram mass. The PM-1 and PM-3A core's uranium is enriched to 93.5 percent and contains 29.2 kilograms of such material. In any case, one agency may not ship more than 160 grams of  $U^{235}$  in class II packages, during a given 24-hour period. This is approximately 0.59 percent of a PM-1 core or a little more than 4 of the 741 tubular fuel elements contained in the core.

Shipments of new reactor fuel in any substantial quantity, will then correspond to the USAEC's class III shipments, because of the quantity of fissile material involved. Class III shipments are those which are approved on the basis of careful control of the conditions under which they will be transported as contrasted to class I and class II shipments in which more dependence upon packaging is stressed. USAEC regulations do not permit the mingling of class I or class II packages with class III shipments. The particular conditions of shipment of class I or class II packages do not require specific Commission approval whereas those of class III shipments do. Class III shipments are formally defined as those shipments which will not fit within the specifications of class I or class II.

A regular class III package may contain a maximum of 10.0 kilograms of  $U^{235}$ , under certain rather rigid conditions of moderation control. Again, a complete core of a military nuclear power reactor will usually contain more than this amount of  $U^{235}$ . The USAEC would then designate this as a "Special Class III Shipment" which the Commission will authorize only upon careful scrutiny and analysis of the conditions of shipment. Assumedly, the normal class III packaging requirements would hold for "Special Class III Shipment" also. They are liberally interpreted and paraphrased as follows:

- 1 Resistance to crushing and fracture shall be at least equivalent to that provided by Schedule 40 steel pipe.
- 2 The bottom plate shall be equivalent in strength to a plate, equal in thickness to the wall of the container, welded or threaded to the bottom of the container.
- 3 The top closure which may be a flanged or gasketed cover or a standard pipe cap shall be equivalent in strength and leaktightness to the container itself.
- 4 The package shall be capable of withstanding a drop on any side, including the top and bottom, onto an unyielding horizontal flat surface from a height of 30 feet with no loss of contents from the inner container (if there is one included, within a "birdcage" spacing arrangement) or inside of the package and with no more than a 10 percent reduction of the

spacing measured from the outside of the inner container to the outside of the outer container (if appropriate).

5 The surface of the birdcage (if one is needed) shall be so designed and constructed that spacing will be maintained under normal conditions of transport, that overriding or interlacing of packages shall be prevented and that it will be capable of withstanding a free fall of 3.5 feet onto an unyielding flat horizontal surface no larger than 6 inches in diameter without exceeding the ultimate strength of the structural material of the outer surface of the birdcage.

6 The package shall be capable of withstanding exposure to the first ten minutes of the standard one hour fire (see appendix III, paragraph 14.2) with no loss of contents from the inner container and no more than a 10 percent reduction in any spacing measured from the outside of the outer container.

7 When compliance with the criticality criteria requires that like packages in a shipment be arranged only in a planar array and not stacked, there shall be affixed to the top of each birdcage or container an angle iron tripod, frame or other similar device. The following legend shall be legibly indelibly printed in red letters at least one inch high on a white background, painted on or securely affixed to the top surface of the container:

CLASS III SHIPMENT  
SPECIAL ARRANGEMENT  
THIS END UP  
DO NOT STACK

8 Where there is no birdcage and interior container the provisions of paragraph 4, pertaining to the birdcage, shall be meant to apply to the exterior surface of the container, the provisions of 5 may be deleted, and the 10 percent volume reduction upon exposure to fire specification will be meant to apply to any reduction of the original interior dimensions.

The USAEC requires that class III packages must be shipped in accordance with one of the following procedures:

- 1 As a shipment having exclusive use of the vehicle
- 2 Under escort of a qualified courier
- 3 Under written certification of assurance that shipment will be made completely with the vehicle on which it is originally loaded and that no cargo containing source or special nuclear material, explosive or flammable materials be transported in the same vehicle.

4 The package will not be placed in any vehicle containing source or other special nuclear material, heavy water, beryllium, graphite, or flammable or explosive material, or at any time during loading, transportation, or delivery be closer than 20 feet from such material, but may be transported in the same vehicle with materials other than those specified in this paragraph, when such other materials are included in the license granted by the USAEC.

As may be seen from the previous resume of the USAEC's packaging specifications and discussion of the "unit" system, the USAEC tries to avoid making flat statements about critical mass requirements or  $k_{eff}$  (the neutron multiplication factor;  $k_{eff} = 1$  occurs when a nuclear assembly is just barely critical); however, the position taken, especially in 10 CFR 70 is that the maximum value  $k_{eff}$  should reach, in transport is 0.8. This may prove to be a valuable point, if future Air Force requirements for shipping nuclear fuel involve highly unusual situations which do not lend themselves well to the criteria detailed in 10 CFR 70 and 10 CFR 71.

(c) IAEA standards

The "Regulations for the Safe Transport of Radioactive Materials" published by the International Atomic Energy Authority<sup>19</sup> are a little more concise and less specific regarding the shipment of reactor fuel. They state:

"In evaluating the inherent safety of the shipment one of the following alternative approaches shall be used: either

"(a) The effective neutron multiplication factor ( $k_{eff}$ ) of the system shall not exceed 0.9; or

"(b) The following safety factors shall be applied to allow for uncertainties in the experimental or calculated data used:

"(i) where mass is the controlling factor, the permissible value in any single package must not exceed 80% of the critical mass under the conditions of packing, with due consideration for built-in neutron absorbers; or

"(ii) where geometry is the controlling factor, the permissible value for each controlling dimension must incorporate a 10% safety factor."

As with 10 CFR 71, the IAEA allows the shipper to take credit for built-in neutron absorbers, provided there is an assurance that such absorbers will not change their effectiveness or position relative to the fuel elements as a result of mechanical shock or meltdown encountered during normal shipment or as a result of the maximum credible incident. Also, the IAEA specifications call for considering the container full of, and surrounded by water, and requires the shipper to anticipate and preclude the chance that other special nuclear or reflector material might be placed in close proximity to the package, during shipment, trans-shipment, loading or unloading. The class I and II designations made by the USAEC have their counterparts in the IAEA specifications, although not in the exact form.

(d) Recommended container criteria

With regard to which items from the USAEC and IAEA specifications should apply in the USAF air transport of new reactor fuel elements, it is recommended that the packaging provisions for class III special nuclear material, condensed and paraphrased in previous paragraphs apply. The IAEA specification of  $k_{eff} = 0.9$  is not as conservative as the USAEC's  $k_{eff} = 0.8$  and, in some cases a fissile mass greater than 80 percent of a critical mass must be shipped as an integral unit.

In addition to the USAEC's specs, however, it is felt that the following specifications should be added for containers intended for air

transport on USAF aircraft, because of the particular environments to be encountered in air transport and the handling one may expect these types of packages to receive:

1 If fuel element arrays are to be shipped with neutron absorber materials in place, and if these materials are required to meet the nucleonics ( $k_{eff} = 0.8$ ) criteria, mechanical interlocks and fittings requiring special tools to disengage them should be used to lock these materials in place.

2 Materials of which the container or any components or internal structures are constructed shall be such that there is no significant chemical, galvanic, or other reaction, between them or, with fuel elements. Military Standard MS 33586, "Metals, Definition of Dissimilar," will apply. Metals so classified as dissimilar will not be brought into intimate contact with one another, unless it can be proved that galvanic interaction will not occur. All welding and brazing of the cask shall be performed in a workman-like manner, free of significant defects, and shall provide a mechanical joint efficiency of not less than 85 percent. The melting point of any brazing material shall not be lower than 1000°F.

3 The container shall be provided with adequate hooks, handles, trunnions, skids, base plate, or other devices which will permit adequate tie-down and support during transport and facilitate normal handling. Any device which is attached to the container or could be employed to tie the container down during transport shall be sufficient to withstand a static force having a vertical component of 2 times the weight of the loaded container (up) and 4.5 times the weight of the loaded container (down) and a horizontal component of 10 times the weight of the loaded container without exceeding the yield strength of the materials in the device. Any device which is attached to the container and which is designed to lift the container shall be capable of lifting 6 times the weight of the loaded container without exceeding the yield strength of the materials in the device. Any device which is attached to the container and which is designed to lift the lid shall be capable of lifting 6 times the combined weights of the lid and contents of the container without exceeding the yield strength of the materials in the device. If this device is attached to the lid during transport, it shall be capable of withstanding a static load

equivalent to 6 times the weight of the entire container and contents without exceeding the yield strength of the materials in the device.

4 The allowable floor loading distribution, to be achieved by proper design of the pallet upon which the container is to be mounted, will be taken to be as specified in the appropriate Air Force dash 9 technical order for the particular aircraft in which transport is planned.

The pallet design should be compatible with the 463L Materials Handling system being developed for MATS (and other) aircraft.

5 The container shall be capable of withstanding vibration incident to shipment without impairing the integrity of the closure or of the container itself. (Frequencies and amplitudes to be regarded as representative of those to be encountered in aircraft cargo compartments may be found in section 10 of appendix III of this report.) The container and its ancillary equipment (if any) shall be able to endure these vibrations at each specified frequency for a period of three hours.

6 Means shall be provided for the application of a heavy-duty lock and a seal so that the container cannot be opened without destroying the seal and either unlocking or forcing the lock.

7 As a pressure differential may be expected to develop across the container seal due to altitude variations encountered in transport, the container design shall be capable of maintaining the closure integrity at all ambient pressure conditions which can be anticipated. Means shall be provided for safely equalizing the internal pressure of the container with the pressure of the atmosphere at any time during transport.

8 The container shall be capable of withstanding any severe climatic environmental conditions which may be encountered during shipment, or storage as specified by Military Standard (Mil Std) 210. The container designer may apply for relief from any articles of Mil Std 210 which apply only to geographical areas to which, or through which, shipment of the container could never be made.

9 The container is to be marked according to the appropriate provisions of Air Force Manual 71-4, at all times. In particular, AF form

1532 or 1533 should be clearly filled out and attached to the container when loaded. AF form 1595 should be attached to the cask whenever it is empty. In addition, the following legend should appear on the side of the container at all times, in red letters at least 2 inches high set upon a white background.

DANGER  
THIS CONTAINER, WHEN LOADED,  
CONTAINS FISSIONABLE NUCLEAR MATERIAL!  
UNDER NO CONDITIONS ARE UNAUTHORIZED  
PERSONNEL TO TAMPER WITH OR OPEN  
THIS CONTAINER!

One may readily see that new fuel containers are going to constitute much less of a purely mechanical problem than, say, irradiated fuel element casks. The new fuel containers are much lighter and this greatly diminishes handling and floor loading distribution problems. There is no sensible heat to be dissipated and hence another problem is eliminated. There is no coolant to leak, generally, and even if there is some water inside the container, one is not worried about contamination resulting from leakage. The safety analysis of new fuel containers concentrates upon the prevention of criticality. With spent fuel containers in which a whole core is to be shipped this danger also exists, however, and in comparing irradiated and unirradiated fuel containers, the fact that the latter require no heavy walled shielding, which delights one at first glance, also means that the margin of safety afforded by the massive sidewalls of the irradiated fuel cask is diminished with the unirradiated fuel element container.

The 30-foot drop test is, as with irradiated fuel, meant to simulate a mishap occurring during loading rather than a major aircraft accident. Again, it is unrealistic to demand that packaging of the dimensions required to ship reactor cores or fuel elements withstand such high-velocity impact conditions. Under normal handling mishaps, however, the packaging must absolutely contain its charge in order to preclude the formation of a critical assembly upon the ejection of the core elements.

As mentioned previously, new reactor cores which are being shipped in toto will almost always have all the neutron absorber rods, which are used to control the reactor, firmly anchored within the core. The fixture used for this purpose with the PM-1 and PM-3A cores is shown in figure 14. As recommended previously, rather special tools are required to disengage and lift this fixture from the top of the core shroud and thus enable one to withdraw the neutron absorber control rods or other neutron poisons from the core. Actually, fixtures requiring even more specialized tools for this job would be desirable, from the safety standpoint.

The device shown in figure 14 remains firmly atop the PM-1 and -3A core when it is placed within its shipping container, which is shown in figure 15. While this container has not been analyzed for compliance with the criteria delineated above, it is roughly illustrative of the type of container one may expect to have to deal with in the shipment of new reactor cores.

Often neutron poison plates or strips are inserted in cores or core elements, to lower the reactivity of the assembly. Sometimes this is performed in conjunction with the retention of the control rods in the core and sometimes it is done in lieu of the control rods. The criterion that these poison materials must remain effective and in place during the maximum credible incident is paramount. Usually two types of materials are used for this job. One is boron steel plates which may be inserted in the core in a manner such as shown in figure 11. The other material, which was used in the initial shipment of the PM-1 and PM-3A cores is borated polyethylene, fabricated into strips which fit into the coolant flow channels of the core. This borated polyethylene material is definitely not recommended for such use. Polyethylene begins to distort at 122°F and, as such, it is highly unlikely that it would retain relative position in the core, upon application of the 10-minute fire test, as specified. A material such as boron steel which does not distort appreciably at the temperature encountered in the fire test (maximum temperature 1300°F) is mandatory if the proposed criteria are to be met when reliance is made upon such materials to meet the nucleonics specification (as may well be necessary when one remembers that the core must be assumed to be submerged and flooded with water, for the determination of the subcriticality condition).

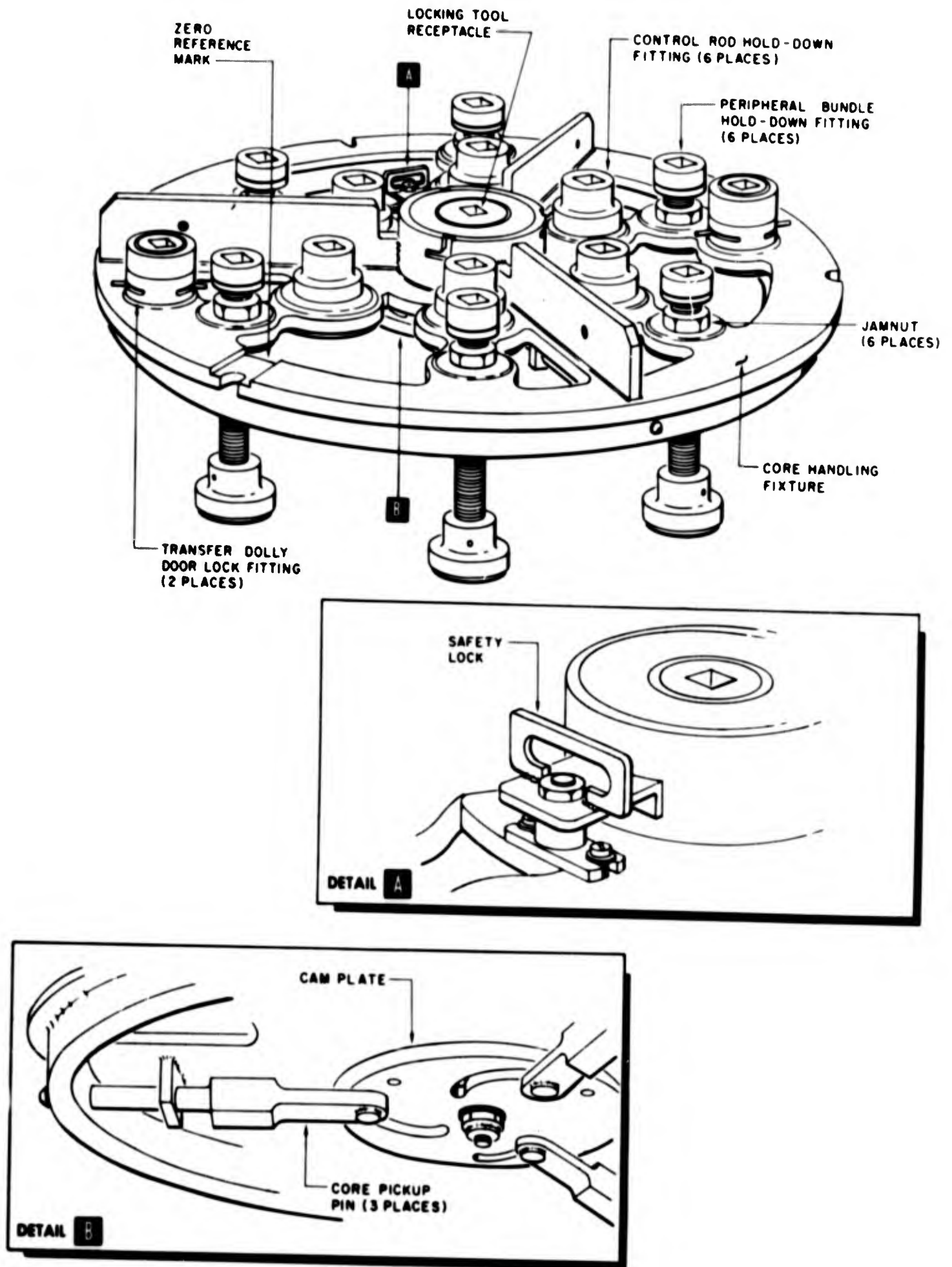


Figure 14. PM-1 core handling fixture

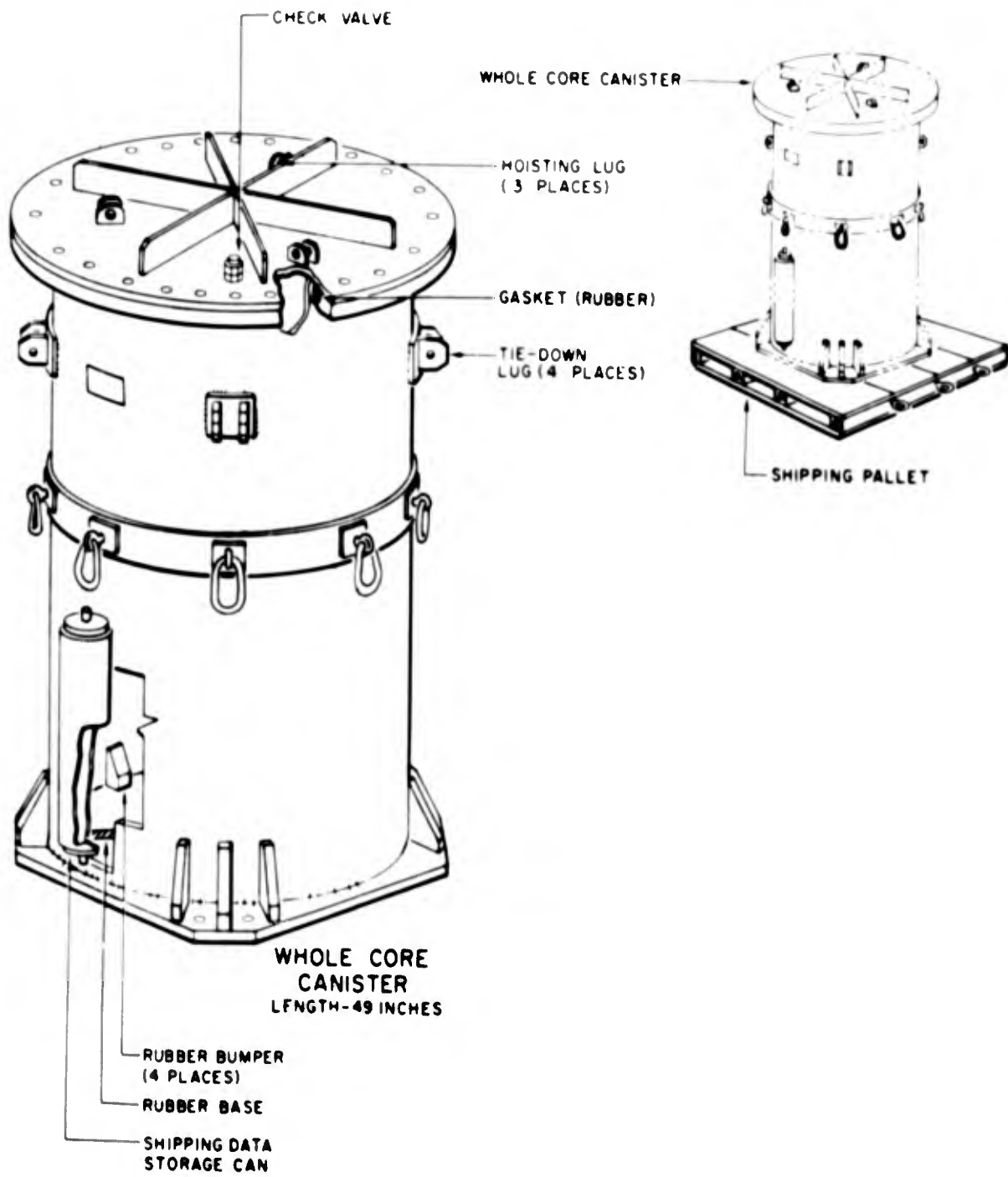


Figure 15. PM-1 new core canister

Finally, one may remember that, at the beginning of this section, it was stated that the problem of criticality prevention, the prime safety consideration in the shipment of this type of material, may be avoided by shipping a given core in parts. Actually, there are two arguments that may be raised against such shipment in parts; first, it will cost more. The individual packaging approach will undoubtedly result in having to ship a greater total weight which will result in a higher transportation cost. Secondly, if the packages are shipped together, exclusion distance criteria will probably have to be established and adhered to, and contraptions such as birdcages, gross dissipators, or cargo space, may have to be employed. If birdcages are not employed, correct operational procedures may have to be employed to ensure compliance with safety rules. This would run against the basic tenet of nuclear safety philosophy which holds that maximum reliance should be placed upon equipment design and minimum reliance upon correct operational procedures.

In short, the systems project officer for a remote nuclear power plant development program will have to determine whether the nature of the hardware and the transport channels to be employed dictate the shipment of new reactor cores in subcritical sections, simultaneously or sequentially, or whether the safety conditions can be controlled enough to ship the cores in toto.

As regards the method of proving that a given package design complies with the established criteria, the same philosophy as stated for irradiated fuel element containers should apply. That is, the following techniques, listed in the order of desirability, are recommended: the results of engineering assessment of the package design, with all assumptions made for the purpose of such assessment stated; tests of models of packaging details or mock-ups representing methods of construction; extrapolation from results of tests of similar designs with similar construction features; reference to shipping experience with package of similar design; other information, argument, or evidence; or actual tests of prototypes of the design.

(3) Radioactive wastes

Section 2a(3) has discussed some of the sources of radioactive wastes in a typical military nuclear power plant. These are dissolved contaminants in the make-up water, primary system structural materials, which have corroded or eroded away or been knocked out of their lattices by recoiling fission fragments or neutrons, and fission products which have leaked out through a fuel element cladding failure. Other possible sources of radioactive waste in the plant include the water from the "hot" laundry machines, and, usually, materials dumped into all the floor and sink drains in the plant (especially that from the radiochemistry lab). Also discussed was the need to concentrate these wastes, usually by means of evaporation, into a sludge.

(a) Stabilization

The packaging of this sludge in drums or shielded containers for shipment is the job of designated members of the plant crew. As discussed previously, it is highly desirable that the wastes be stabilized in a solid form. Often cement is mixed in with the sludge, when it is loaded into its shipping drum. This may be mixed on a 2 for 1 volume basis (sludge to cement) and is often done for wastes intended for dumping into deep ocean. Sometimes highly absorbent material, such as diatomaceous earth, is used to absorb and stabilize the liquid waste. In this case, an amount of such material sufficient to absorb all the liquid should be added. Cement is preferable.

If the container is to be reused, however, the formation of a solid, such as would occur with the addition of cement to the batch, would be a headache. This is unfortunate because with high level waste it becomes more desirable that it be fixed in solid form and yet it is the high level waste that will require the expensive, shielded container which one would hope would be reusable. Perhaps a parting agent can be applied as an interior lining to a reusable container which would, in effect, allow the solid chunk of fixed waste to separate from the container, at its destination.

(b) Container criteria

Industry has not formulated such extensive criteria for containers of low level waste as it has for, say, irradiated fuel elements, because the hazard involved is much smaller. Irradiated fuel must be shipped

to one of the two reprocessing facilities in this country, but low level waste is usually disposed of on site or at any of several sites in the country. The long distance shipment of such wastes is rather unusual. The following are the prime consideration in the packaging of radioactive wastes:

#### 1 Surface contamination levels

As with casks intended for use in shipping irradiated fuel, the shipping agency should survey representative parts of the filled container for external contamination by wiping an area of approximately 100 square centimeters with clean absorbent paper, applying moderate finger pressure, and measuring contamination on the paper through standard counting techniques for beta-gamma and alpha activity. Surface contamination so measured shall exceed neither 4,000 disintegrations per minute per 100 square centimeters of beta-gamma activity nor 500 disintegrations per minute per 100 square centimeters of alpha activity.

#### 2 Exterior radiation levels

While it is expected that few radioactive waste packages will ever exceed acceptable limits, these shall be established such that the direct external radiation level of a package intended for shipment shall not exceed 200 milliroentgens per hour at any accessible surface or 10 milliroentgens per hour at a distance of 3 meters from such surface.

#### 3 Heat dissipation

As with the anticipated exterior radiation levels, a very small amount of heat is expected to be generated in a container of low level waste. The heat shall be dissipated in such fashion, however, as to completely preclude boiling of liquid wastes (if they are not in a stable, solid form) at any time during shipment and so as to never cause a surface temperature of more than 180°F.

#### 4 Materials

Materials of construction shall be chosen that will not interact with the radioactive waste contents of the package and that will be capable of easy radioactive decontamination. Stainless steel is preferred for a surface contacting the waste, save, of course, for gaskets. Should the waste

charge be acidic in nature, it should be chemically altered so as to be moderately basic, thus reducing the danger of corrosion.

5 Structural integrity

The container should be so designed as to be capable of withstanding a drop from the greatest height the package will "see" during transport, onto a hard, flat, unyielding target, without releasing its contents. It is this suggested specification that makes the stabilization of radioactive sludge by the addition of cement especially desirable for air transport.

6 Pressurization

The container shall normally be pressurized at ambient pressure. The container design and gasket seal must be capable, however, of retaining the contents upon a drop test, as specified in the preceding paragraph.

7 Tie-down fittings

Tie-down fittings on the package shall be capable of withstanding the following static loadings:

Longitudinal	8.0 g forward, 1.5 g aft
Lateral	1.5 g to either side
Vertical	4.5 g down, 2.0 g up

8 Pallet mounting

The pallet shall be designed so that the allowable floor loadings of the aircraft to be used for transport, as specified in the applicable dash 9 Air Force technical order, will not be exceeded. The pallet should be compatible with the 463L Materials Handling System equipment to be installed aboard C-130's, C-133's, C-135's, and C-141's in the future, to facilitate easier cargo handling.

9 Marking

The radioactive waste container shall be marked according to the appropriate provisions of Air Force Manual 71-4 "Packaging and Handling of Dangerous Materials for Transportation by Military Aircraft." In particular, AF form 1609 must be properly filled out and attached to the package, regardless of the modes of transport to be used; i. e., even if all transport is to be con-

ducted via military channels, form 1609 should be attached, for the purpose of warning military personnel involved to avoid unnecessary contact with the package.

(c) Nonrechargeable demineralizers

Occasionally, one may encounter, with some plants, a primary coolant purification system which uses a nonrechargeable demineralizer cask. While this item of equipment is not recommended, a cask design which permits resins to be flushed to the concentrator being preferable, one may encounter it in older nuclear power plants. The SM-1, for instance, has such an undesirable feature. The contractor, however, designed a shielded shipping container for spent resin casks. Figure 16 is a drawing of that container. This container incorporated a gasketed lid to back up the quick disconnect seals provided in the demineralizer nozzles. A load spreader pallet is an integral part of the container design and, while an engineering analysis has not been made, it is assumed that this design would meet the above criteria. In the design of a remote military nuclear power plant, it is highly recommended that this nonrechargeable type of demineralizer cask, which cannot be flushed to the waste concentration system, be avoided. As one can see, this would simplify at least this one aspect of the radioactive waste shipment problem.

(4) Contaminated components and tools

The primary hazard to be anticipated with contaminated components and tools is that, in the handling of these items, someone may pick up alpha- or beta-emitting material and ingest it into his body via the "hand-to-mouth" route. Direct radiation would not be expected to be a problem. Components and tools in this category would have to be at a very low level of contamination, otherwise work could not be performed, to bring the components back into operational status, or with the tools, and they would be useless. No appreciable direct radiation is to be expected when surface contamination is at such a low level.

The primary consideration in packaging these items is then to ensure that they cannot be handled directly from the point of their origin to their destination. There are extremely simple packaging techniques capable of satisfying this requirement.

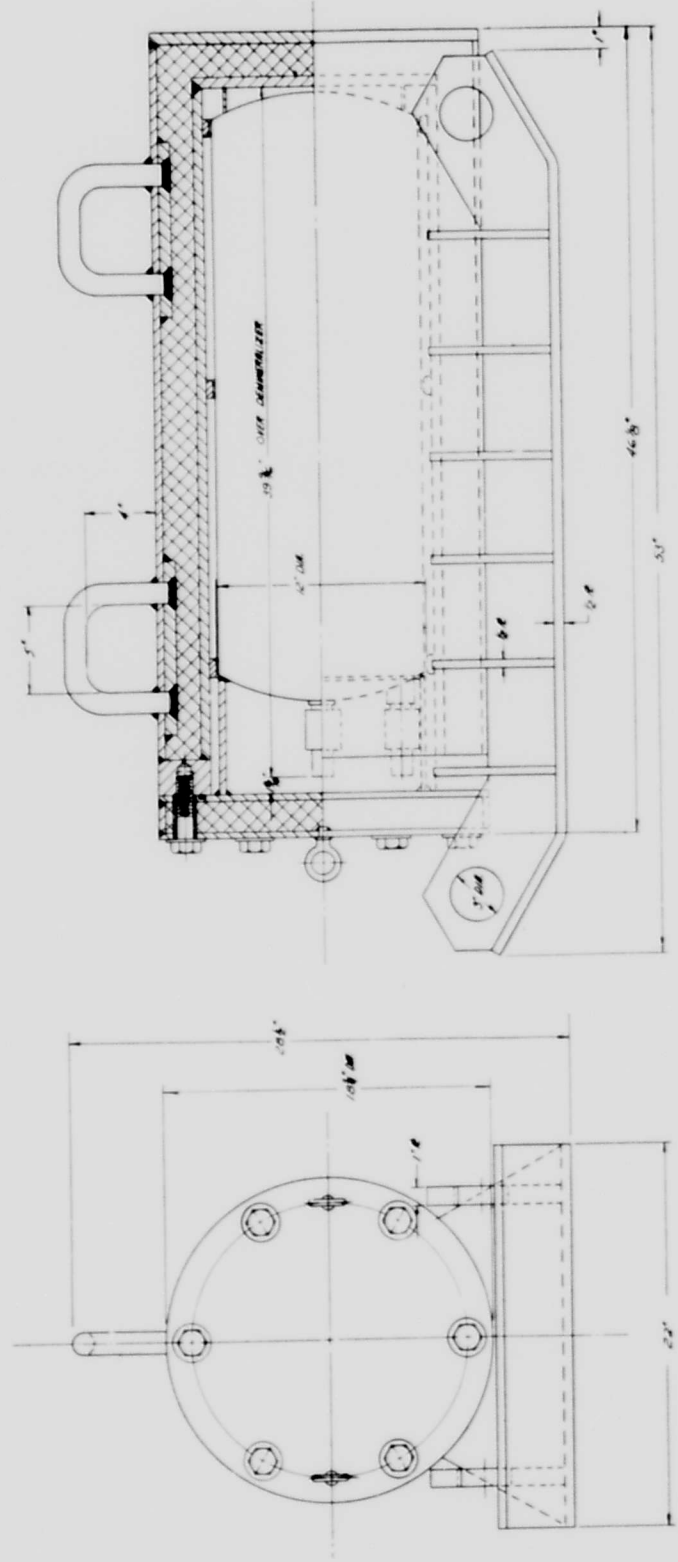


Figure 16. SM-1 demineralizer resin bed shipping cask (shielded)

(a) Packaging

One such technique, commonly used in the atomic energy industry, is the wrapping and sealing of the item in heavy-gage polyethylene sheet. Wooden boxes, with appropriate packing, are also satisfactory. Containers which deteriorate upon exposure to moisture are discouraged.

The nature of the contents and a warning not to handle them should be clearly marked on the package in addition to the labeling required by Air Force Manual 71-4 (which specifies AF form 1609 or 1610 for gamma and corpuscular ray emitters and form 1532 or 1533 for material emitting corpuscular (alpha or beta) radiation only). The radiation contamination levels (usually in milliroentgen per hour on contact or disintegrations per unit area per unit time) registered by the shipping agency/health physics personnel upon delivery for shipment should also be included in the labeling.

(b) Complete plants

A slightly different situation may be encountered if an entire plant is to be moved. Such a situation is being faced with the PM-2A nuclear power plant, presently at Camp Century, Greenland. It is not proposed that the PM-2A be moved by air as it was never designed to be air transportable, but the problems are illustrative. Materials very close to the reactor core, in the primary system, not only have high surface contamination due to contact with the primary fluid but are also radioactive themselves as a result of radioisotopes formed by neutron bombardment. Obviously, such items of equipment are not meant to be directly worked on by repair or maintenance personnel but, rather, will be relocated with an eye to reassembly and possible resumption of operation. This is certainly a very special and unusual operation when compared even to the shipment of irradiated reactor fuel elements and it is rather risky to generalize upon any provisions regarding such an operation. It is recommended, however, that any such item not be presented for air transport until the radiation level at the surface falls to 200 milliroentgens per hour at a distance of 3 meters to a value of 10 milliroentgens per hour.

(c) Radioactive scrap

With regard to material which may be classified as "radioactive scrap" and is not to be repaired and reused, it would be preferable to

ship it along with the liquid radioactive waste, if possible. As liquid waste is charged into the appropriate shipping containers and ready for the addition of a stabilizing agent, solid waste which is small enough to fit in the container should be added. When the stabilizing agent, usually cement, is added and sets up, both solid and liquid waste are fixed in a safe form. If the items of solid waste are too large to fit in the liquid waste container, then they should be decontaminated, packaged, and handled just as the reusable components and tools discussed previously. Of course, the level of surface contamination may be higher but the direct radiation criteria should not be exceeded. If the material is merely scrap, there should be no problem involved in allowing sufficient time for its activity to decay down to acceptable levels.

(5) Aerospace reactor systems

As discussed in section 2. b. of this report, the only reason for transporting an aerospace nuclear reactor power system would be (1) to simplify the shipment plan by eliminating a lot of transfers, temporary lay-overs, etc., (2) to ensure a higher degree of military security, or (3) to achieve a savings in time. At the present time there are no known plans to effect such a shipment. A discussion of some of the more technical aspects of shipment is included, however, because of the similar safety considerations that exist between such shipment and the air logistic support of a remote, terrestrial, military nuclear power plant.

The only reactor space power system which has been seriously considered for orbital launch is the SNAP 10A (see figure 6). While in the past firm plans were made to perform an orbital flight test of this system, at this writing the decision as to whether the SNAP 10A will be tested in space is pending. If it is to be launched, however, it will be transported via trailer truck from the contractor's facility at Santa Susana, California, to Vandenberg AFB, California, and from there to the Point Arguello launch pad (after certain assembly and checkout operations are accomplished in a special maintenance, assembly and disassembly (MAD) building at Vandenberg); it will not be transported by air.

Hopefully, the reader will realize that the packaging and shipping operations associated with a space-type reactor depend more upon the type of

reactor system concerned than is the case with the packaging and shipping of terrestrial reactors. This is a most difficult subject upon which to generalize. An attempt has been made to dwell only upon points which are not peculiar to the SNAP 10A power system, however. The SNAP 10A is illustrative of space reactor systems to follow because (1) it has a compact, "fast," reactor core; (2) it utilizes a liquid metal combination (a sodium and potassium mixture called NaK) as a heat transfer fluid; (3) the reactor core is controlled externally by the reflection of fast neutrons back into the reactor core rather than by the absorption of neutrons by poison control rods placed within the core.

As in the shipment of new reactor fuel to a remote, military nuclear power plant, the buildup of fission products within the core, as a result of zero power testing performed by the contractor, will be negligible and the core will emit no biologically damaging radiation as long as it is adequately "shut down." The prime safety consideration is then, again, the preclusion of nuclear criticality. With the inclusion of liquid metals, however, one must also ensure their adequate containment, as they are very corrosive, highly toxic, and some of them (NaK for instance) react with water in an almost explosive fashion. Also, some of the other materials used in the core, including beryllium and the uranium fuel, when released as vapors or small particle-size aerosols, are dangerous when inhaled and ingested into the human body even in relatively small amounts. The approximate amounts of such toxic materials in the SNAP 10A power system appear below<sup>20</sup>

<u>Material</u>	<u>Quantity (lb)</u>
Uranium (93% U <sup>235</sup> )	10.0
Lithium hydride	150-300
Beryllium*	80
NaK	40

\*Most of the beryllium is contained by the removable reflector drums which were to be shipped in a separate container from the reactor core.

(a) Reactor configuration

The configuration will usually be altered for shipment, to place the reactor in a less reactive condition. With the SNAP 10A the drums containing the neutron-reflecting material, which are rotated in a programmed sequence in toward the core to achieve criticality, are removed from around the fuel element canister. In their place is positioned a sleeve of neutron-absorbing material. This sleeve is to be made of a material capable of withstanding exposure to high temperatures and, along with the hardware which holds it in place, should be capable of remaining in position even under very high g loadings. The sleeve will be removed and replaced with the reflector control drums in the special MAD building at the missile range as a part of the prelaunch checkout and test procedures. The shipment of the drums should be made in separate container and on a different vehicle.

(b) Encapsulation

During transport the reactor power system will be encapsulated in a container of high mechanical integrity. The reasons for this are many:

- 1 To protect the system in the case of impact
- 2 To prevent the contamination of the reactor payload by allowing the unit to be kept in an inert, clean atmosphere.
- 3 To establish an additional barrier to penetration or envelopment of the core by water.
- 4 To permit better monitoring of any neutron multiplication taking place, which would be used as an indicate of an approach to criticality.
- 5 To permit easier monitoring of chemical (namely NaK) leakage.
- 6 To provide containment for corrosive and toxic materials, such as NaK, in the event that they leak in quantity.
- 7 To facilitate the isolation of the auxiliary power unit from the shock and vibration which may be encountered in transport.

The SNAP 10A container is roughly shown in figure 17, mounted upon a trailer. One would expect that a container of similar design features, though perhaps built to slightly more rigorous specifications, would be employed if the SNAP 10A were to be airlifted. The container is designed

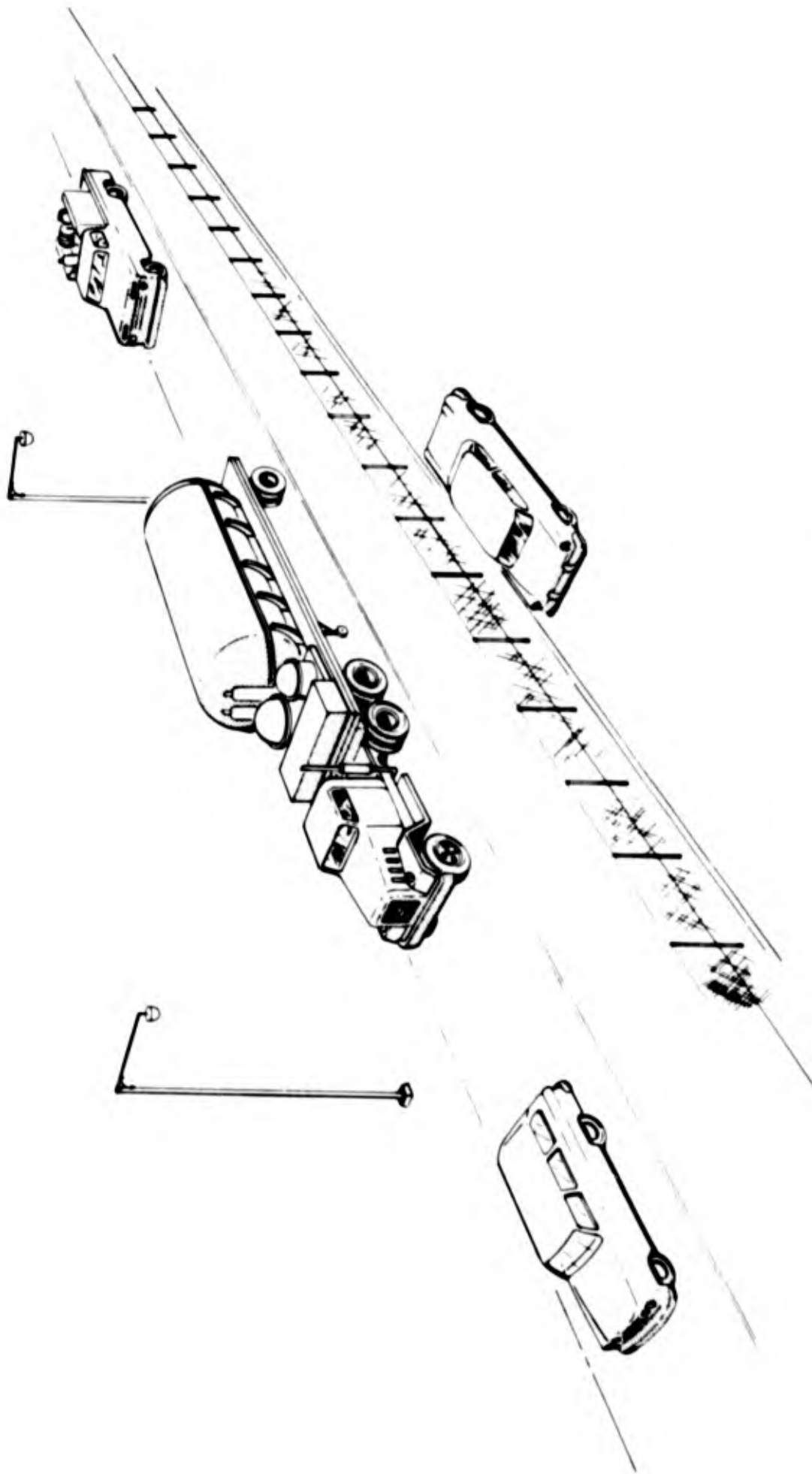


Figure 17. SNAP 10A - shipping container for road transport

to contain an internal pressure of several psig (pounds per square inch, gage). For air transport this specification would undoubtedly have to be upped another 10 psig, or so.

(c) Package instrumentation

With the SNAP 10A a low-level neutron source (a combination plutonium-beryllium source) is attached to the shipment to provide a detectable background level for the neutron monitor instrumentation.

As it is to be expected that reactor auxiliary power units will be shipped in a configuration which lacks some of the components required to take the reactor to criticality and has substituted items such as neutron-absorbing sleeves for them, one can see that only in an extreme accident could one expect to find neutron multiplication, much less criticality. This leads one to wonder then, whether it is not unduly pessimistic to routinely instrument for neutron multiplication during shipment and whether such instrumentation could not be eliminated without degrading safety. Nonetheless, such instrumentation was to be included in the SNAP 10A shipping package. This should not be considered as a precedent for the design of future containers, however, without a careful examination of the other safety features of the packaged auxiliary power unit.

The packaging design also has instrumentation to detect the leakage of the liquid metal, NaK. The container, in shipment, will be purged and pressurized with argon which will aid in the detection of such leaks. Shock, pressure, and temperature sensors are also provided with the SNAP 10A container and read out on recording instruments. In the case of the neutron and NaK leakage instruments alarms, the indication is made in the cab of the tractor hauling the package.

(d) Packaging criteria

Regarding the packaging criteria which should be levied upon an agency wishing to transport an item such as the SNAP 10A by air, it would appear that the above provisions would be complete enough and satisfactory, provided it could be established that the packaging and reactor system would remain unchanged upon exposure to the military aircraft environment.

In particular, a determination should be made that such space reactor packaging is capable of withstanding the same environments specified for irradiated fuel containers in appendix III, sections: 6 (Temperature), 7 (Humidity), 8 (Blowing Sand and Dust), and 10 (Vibration).

The familiar tie-down criteria of 8 g's horizontally, 4.5 g's down, and 2 g's up will apply as should the dissimilar metals specification, MS 33586. The container should be compatible with the 463L Materials Handling System presently being developed. This will greatly enhance the loading, unloading, and tie-down operations involved in the air shipment operation.

Regarding container marking, the package will be under escort at all times (see section 5. b. (5)) and the device will probably be classified. As such, no marking will be attached, at least to the exterior surfaces of the container.

Presumably, the alarm instrumentation, provided as an integral part of the package, will be running continuously, as long as the reactor is in its container. This would require a self-contained power supply, undoubtedly chemical batteries. The batteries should likewise be capable of withstanding the aircraft and climatic environments.

The packaging must also survive a drop test from the greatest elevation it may possibly "see" during ground handling, loading, and off-loading, certainly without having criticality result and hopefully without damaging the reactor system. The same applies for survivability in a petroleum fire such as the AEC "standard fire."

In summary, it is expected that space reactor systems will not be shipped in a fully operational configuration, but rather that they will be shipped in parts and with hardware attached that will render them highly sub-critical, even in a rather severe accident situation. Packaging will be essentially self-contained, furnishing a pressurized, inert atmosphere and the hazard instrumentation, which will monitor and alarm chemotoxic leakage and, perhaps, neutron multiplication, will be an integral part of the packaging. The container into which that portion of the auxiliary power system containing the nuclear fuel fits will have high physical integrity and, under nonaccident conditions, will be capable of maintaining a finite level of internal pressurization.

The packaging shall be capable of exposure to the normal military aircraft environmental tests with no resultant deleterious effect and criticality will not be possible even upon the application of drop and fire tests.

(A) Radioisotope generators

(a) Generator design

Radioisotope generator systems designed to date have had tremendous structural integrity in order to prevent the release of isotope material in the event of any conceivable accident. It has had to be established for space units, for example, that they will not release isotopic fuel material upon exposure to the environments accompanying liquid-fueled missile abort fires and shock overpressures from missile aborts, mechanical conditions incident to burial in soft earth, and impact upon solid flat or sharp objects at the fuel capsule's terminal velocity in air. The capsules have also had to be able to withstand one year's submersion in sea water. These are very stringent criteria but the RTGs (radioisotope-thermoelectric generators) lend themselves well to such safeguards. They are inherently small (especially so if they are intended for space use) and must be made to operate at high temperatures without significant weakening of the containment. The isotope fuel material is generally chemically unstable and must be encapsulated in packages which conform nicely to the classification of small, high-density fuel elements. In short, no additional packaging of radioisotope generators should be necessary to meet even the most rigorous mechanical integrity criteria.

(b) Heat dissipation

As mentioned in the discussion of RTGs in the Background section of this report, heat is generated continuously. As with irradiated reactor fuel, it is recommended that the temperature of any surface, accessible to personnel during transport operations, not be allowed to exceed 180°F. Temperatures of 120°F have been more typical of such packages and are more desirable.

(c) Radiation levels

Radiation levels should not exceed the familiar 200 milliroentgens/hr at any accessible surface and 10 milliroentgens/hr at 1 meter

from any surface. Fortunately, one can meet these criteria through the use of birdcages made of strong wire mesh or any other such material which still permits the free motion of air around the radioisotope generator and yet still serves to move the accessible surface of the package out and away from the radioisotope generator. With alpha emitters, such as  $\text{Pu}^{238}$ , shielding requirements should be almost nonexistent. The range of the alphas in the generator structural material will be very small and the few neutrons given off should be negligible. Beta emitters such as  $\text{Sr}^{90}$  will, of course, generate bremsstrahlung which may be more of a problem.

(d) Electrical protection

Most units will deliver at least their rated power whenever a load is attached to the appropriate electrodes and so a barrier should be included to prevent such an accidental occurrence. If the generator is shipped in a birdcage-type package, this and some simple mechanical cover arrangement will probably provide adequate protection.

As with all other radioactive shipments (emitting other than alpha particles) photographic materials should not be brought into intimate contact with the package and such should be clearly stated on the package.

The light weight of these packages should preclude having to design any load-distributing pallets. Should the package weight exceed a few hundred pounds, which is unlikely, the pallet design should be compatible with the 463L Materials Handling System equipment to facilitate ease of handling aboard the aircraft. Tie-downs should meet the usual 2-g vertical (up), 4.5-g vertical (down), 8-g horizontal criteria.

b. Loading and normal flight procedure standards

(1) Spent fuel elements

At the risk of being redundant, it should be reiterated that the philosophy which should prevail in the air shipment of irradiated reactor fuel calls for the inclusion of safety standards in the equipment design, rather than in the reliance upon certain operational procedures and precautions. Even though this point has been heavily stressed, however, there are, of course,

certain standards which must be observed and certain safety priorities which require compliance by the personnel involved in actually making the shipment.

As discussed in section 5. a. (1) it is assumed that a qualified health physicist, military courier will accompany the irradiated fuel element cask from the plant site to its ultimate destination. AFR 71-4, "Packaging and Handling of Dangerous Materials for Transportation by Military Aircraft," states that when class D poisons (the ICC designation) are shipped on Air Force aircraft, and when there is no applicable military regulation in existence (and there is none), the decision as to whether an escort will be required will be made by the "medical officer or flight safety officer, as appropriate." In view of the fact that it is doubtful such personnel will have a comprehensive understanding of the technical aspects of the shipment, one may be quite sure they would be in accord with a recommendation from the sponsoring agency that a qualified courier accompany the shipment. As stated before, the courier should probably be detailed from the nuclear power plant health physics staff. Hopefully, he would be one of their more experienced personnel, fully familiar with the alpha and beta-gamma survey instruments to be used in monitoring direct radiation, radiochemistry lab procedures, personnel radiation exposure control, and hardware and personnel decontamination. In addition, he must be well acquainted with the mechanical design features of the spent fuel cask and, if appropriate, the measurement of temperatures using resistance thermometers or thermocouples. The cask design and the operational plans for the entire shipment have at this stage, of course, already been approved by the agencies responsible for such certification, as specified in section III of this report.

(a) Operations at plant site

The following is approximately the order of operations which will occur at the plant site:

1. Fuel element loading

The time at which fuel elements are loaded, relative to the shipping schedule, will depend upon whether they are meant to "cool" in the cask or not. Some plants have special holders for spent elements, within their spent fuel pits, whose arrangement is determined from criticality and heat-transfer considerations. In others, such as the PM-1, the only place in

which these elements can cool is in the shipping cask, situated in a specified underwater location. With water cooled nuclear power plants, the entire cask loading operation is always conducted underwater. In some cases the pressure vessel head must be removed and the elements, either singularly or in arrays, lifted out and transported to the cooling rack or cask. In others, there are chutes which penetrate the pressure vessel and perhaps, even, the containment vessel, if there is any, and which are appropriately sealed so as to provide the necessary pressure barriers when not in use. In these the fuel elements, usually singly, are lifted out of their position in the core and then placed in the chute down which they slide to the spent fuel tank, there to be picked up and placed in a cooling rack or cask. The entire operation is closely supervised and monitored to prevent undue personnel exposure to direct radiation or inhalation hazards and to ensure that a critical assembly is not made.

During all of these operations, personnel will be shielded by several feet of water. In the PM-1, for example, there is always at least 12 feet of water between any portion of the core assembly and personnel performing the operation.

As discussed previously, a determination of the optimum cooling period should be made for each planned cask design and operational schedule, with an eye toward minimizing the economic factor. Usually, though, this cooling time will be about a year.

## 2. Inserting poison plates

If it is planned to meet the nucleonics criteria by inserting neutron poison plates in the fuel element assembly as shown in figure 11 for the PM-1, the plates should now be placed in position.

## 3. Replacing cask lid gasket

The gasket used to seal the cask closure should be incorporated into the lid of the cask, where it is more accessible, rather than in the cask body, which would be virtually inaccessible when the cask contains any irradiated fuel. This gasket will be under considerable force when the cask is sealed and, as such, will undoubtedly undergo some permanent deformation and should be replaced with each new shipment of irradiated fuel. The operation should be performed at this time.

**4 Placing lid on cask**

The lid should be carefully lowered into the spent fuel pit or tank and properly positioned atop the cask.

**5 Removing cask from loading area**

The cask should now be slowly raised from the spent fuel pit and placed on the working floor or ground. Care should be taken in specifying this operation, to ensure that every surface upon which the cask will rest is capable of supporting its tremendous weight.

**6 Initial direct radiation survey**

The direct radiation levels emanating from the cask should immediately be surveyed and it should be determined whether section 3, Radiation Shielding, of the proposed criteria can be met with the shipment or whether more cooling is required.

**7 Bolting down the cover**

The cover should now be bolted down. A torque to which the bolts should be tightened will be specified for the gasket. This will be registered on a suitable torque wrench.

**8 Lowering coolant level in cask**

The cask vent should be opened and the appropriate volume of coolant water drained off so as to leave the void necessary for expansion and mechanical integrity.

**9 Checking coolant contamination**

A sample of the water drawn off should be checked to determine compliance with paragraph 5.14 of the proposed criteria which specifies maximum allowable gross alpha, beta, and gamma contamination.

**10. Adding of antifreeze**

When required, due to the environmental conditions to be encountered in shipment, antifreeze should be added. It is most important that the fuel elements never be uncovered during this operation as they might heat up to the point where contact with the added coolant would thermally shock

them and result in cladding failure. The void space, previously mentioned, should be preserved.

#### 11 Washing down the cask

The exterior surface of the cask should be thoroughly washed down.

#### 12 Checking exterior contamination

The surface wipe test as specified in paragraph 15.2 of the proposed criteria should be performed to ensure compliance with the allowable contamination levels specified therein. If these limits are exceeded operation 11 should be repeated, perhaps with a strong detergent, and another check made.

#### 13 Pallet mounting

The cask should now be mounted on the shipping pallet, ready for transport. Tie-down bolts and struts should be fully tightened. If a crash frame and shroud have been included in the design of the cask and if the cask cannot be attached to the pallet without first attaching the crash frame and shroud to the cask, they should be firmly attached, at this time. (See figure 18 for a representative illustration.)

#### 14 Pressure-leak testing

The ability of the cask to meet the pressurization criteria without leaking should now be checked. Compressed air should be used to take the internal pressure to the appropriate value specified in paragraph 5.16 of the proposed criteria. All valves, seals, etc., should be checked to ensure that no leakage has occurred.

#### 15 Checking heat-transfer characteristics

The heat-transfer characteristics of the cask should now be checked to ensure compliance with the 180°F external-temperature specification (paragraph 4.1.1 of the proposed criteria) and with the maximum fuel element surface temperature specification (paragraph 4.1.3). If the fuel element surface temperature specification is to be checked by the use of a thermocouple or resistance thermometer element, in place against the interior wall, then

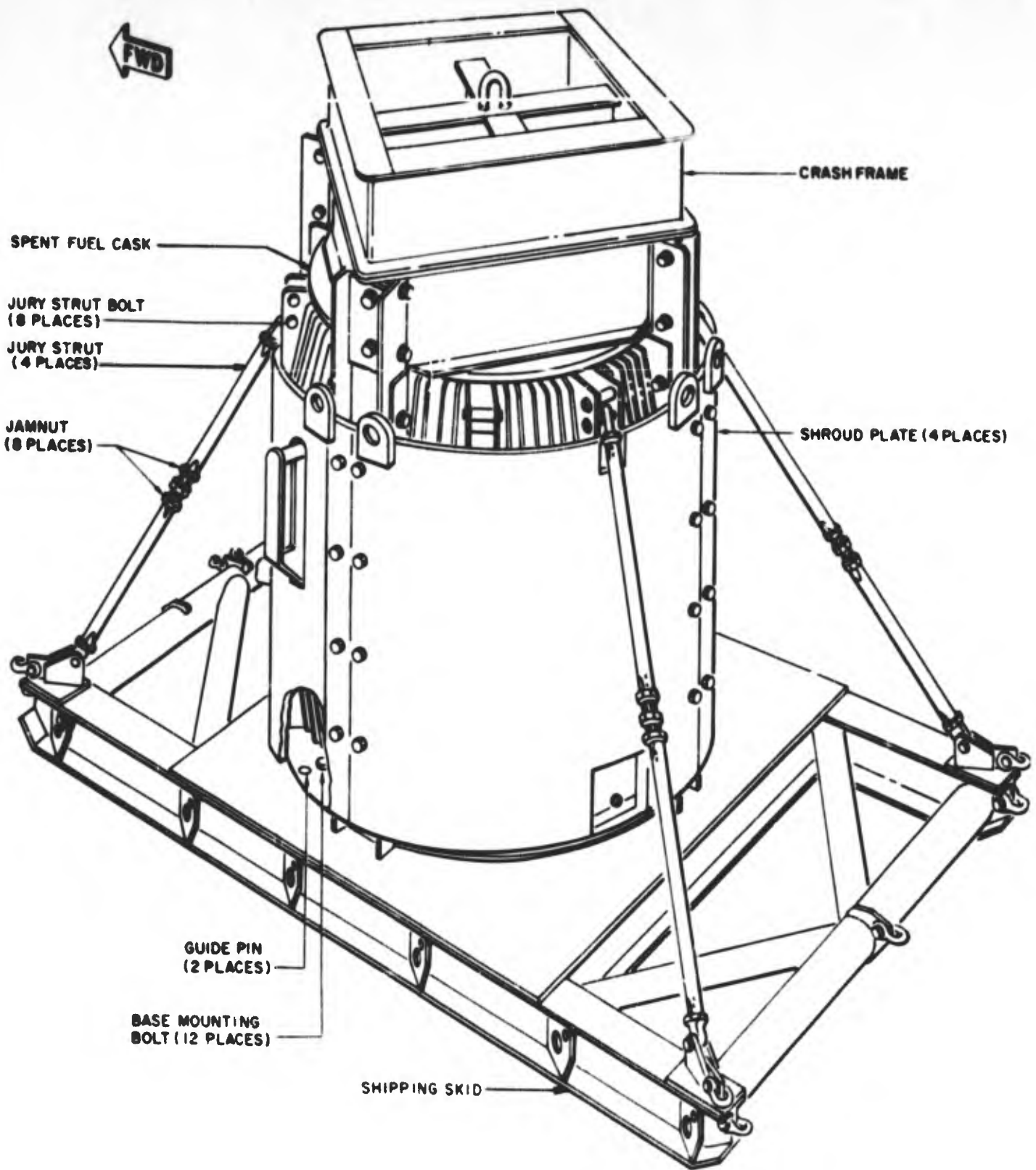


Figure 18. PM-1 spent fuel shipping package

this should be checked with the appropriate meters and reference junction (if thermocouples are used) as previously discussed. If the cask coolant temperature is to be obtained by "indirect" means, such as by observing the rise from an initial internal pressure as a function of time and then determining the internal temperature from a table based upon thermodynamic calculations, the appropriate operational procedure should now be followed.

#### 16 Establishing design pressure

The cask should now be set at the pressure picked for the heat transfer analysis. If this is atmospheric pressure the cask should be vented through the filter. If, on the other hand, the cask is to be pressurized to enhance its heat dissipation capability, this should now be done, using clean, compressed air.

#### 17 Applying closure seal and locking valve

The documentary seal, specified in paragraph 5.2 of the proposed criteria, should now be applied to the lid closure. All valves which might be opened during transport, resulting in the loss of coolant from the cask, should be locked in compliance with paragraph 5.5 of the proposed criteria.

#### 18 Installing crash frame and shroud

If a crash frame and/or a shielding shroud are included in the cask design and if it was not necessary to mount them on the cask when attaching the cask to the pallet in operation 13 they should now be mounted on the cask. The direct radiation survey, mentioned as operation 6, should be made again, to determine whether section 3 of the proposed criteria can be complied with, if the frame and shroud are not added until this time.

#### 19 Proper placarding

The irradiated fuel cask should now be properly placarded, in accordance with the applicable provisions of section 16, Marking, of the proposed container criteria.

#### 20 Transfer to intermediate vehicle

Once the preceding operations have been accomplished, the cask, mounted upon its pallet, is ready for transfer to the vehicle which

will be used as the intermediate mode of transportation between the plant and the aircraft loading point. It is unlikely that a military nuclear power plant will ever be situated immediately next to an airstrip, thus eliminating intermediate transport.

The operations involved in transferring the package to the intermediate transfer vehicle and in loading the aircraft will not be explored in detail in this report. They are little different from any of the operations involved in the routine air transport of a very heavy, dense package. Any qualified Military Air Transport Service or Tactical Air Command loadmaster could specify the entire sequence from the power plant to the reprocessing plant, save only those precautions which should be taken in consideration of the radiation and possible contamination hazard.

During all phases of the loading and unloading of transport vehicles, the loadmaster will be in charge. The radiation health physicist will be his advisor through all operations. The primary concern of the health physicist, if the operations go as planned, will be to minimize the radiation exposure of the personnel performing the operations. In the event of an accident, he will assess and monitor the situation and direct whatever decontamination can be performed. The only realistic accidents one can envision, after which personnel would still be functional, could precipitate nothing worse than the leakage of cask coolant from the package, with the ensuing higher radiation levels and cask wall temperatures.

The transfer of the irradiated fuel element cask from the plant site to the airstrip will, in all probability, be accomplished by tractor-trailer. A trailer ideally suited for this use is the USAF Type C-2 Wrecker Tractor-Trailer. The bed height of this trailer's bed closely coincides with the cargo compartment floor level of the C-130A aircraft. These trailers are available with either 25- or 40-foot beds.

#### 21 Loading trailer at plant site

For this operation a mobile crane of adequate capacity must be available at the plant site. The cask skid will be pulled from its loading point to a location at which it can be lifted by the mobile crane. There the crane will lift the package, at the appropriate points, carry it to the trailer.

and position it in place on the trailer bed. The cask should never be lifted any higher than is absolutely necessary. If 463L system equipment is not to be used, the runners of the pallet, to which the cask is attached, should be coated with at least 1/8 inch of appropriate grease before the cask is placed upon the trailer, as the cask will have to be pulled off the trailer and onto the airplane in the next transfer operation. If the pallet, intermediate transfer vehicles and aircraft are equipped with 463L hardware, the grease will be unnecessary. 463L equipment all has built-in rollers to facilitate easy loading and unloading of vehicles and aircraft.

It may be necessary to install additional shoring on the truck bed, for better load distribution. The design of this shoring, as with the design of all the other operations and equipment involved in this intermediate transfer, will have been previously analyzed and approved as specified in section 3.

It is most important that the orientation of the cask relative to the trailer be specified and that the specification be complied with. This stems from the fact that some of the fuel receiving facilities at the chemical processing plants have special requirements regarding the orientation of casks on trailer beds which are dictated by their layouts and hoist arrangements. For example, the Idaho Chemical Processing Plant requires that casks intended for the 15-ton receiving facility must have their trunnions oriented at right angles to the normal direction of travel of the trailer, while casks intended for the 75-ton facility must have cask trunnions oriented parallel to the direction the carrier normally travels.

The intermediate transfer portions of the irradiated fuel element cask's journey is very similar to the transport of civilian components, which is made in this country on an almost everyday basis. Criteria and standards developed by the Atomic Energy Commission for this transport should apply. In particular, the trailer tie-down scheme should conform to paragraph 72.32(d) of 10 CFR 72 which states that fittings (and thus, by inference, tie-downs) must be capable of withstanding a horizontal static force equal to 10 times the weight of the cask and contents (presumably in any direction in the horizontal plane) and a vertical force of 2 times the weight. This tie-down scheme will have been approved prior to loading, as mentioned before.

Every time the cask is loaded or unloaded onto or from a different transport vehicle, or stored or taken out of storage, the escort should make a thorough check of the cask's condition. This should include a visual inspection and a check on the cask's internal pressure, valve closures and exterior radiation levels.

(b) Loading onto aircraft

When the time comes for the cask to be loaded onto the aircraft the aircraft should already be fitted with any shoring required to properly distribute the load and protect the interior of the aircraft. Tie-down fittings whose locations might interfere with the loading operation must be removed. Skidways are coated with grease, as needed, if 463L equipment is not used. The loadmaster, with the health physicist "at his elbow," directs the loading of the package from the trailer to the plane. The motive force for the operation may come from a prime mover outside the plane or from the portable winch within the plane, regardless of whether or not 463L equipment is provided. It may prove necessary to install some sort of auxiliary truck loading ramps between the end of the cargo ramp and the trailer bed. When the package is in proper position, tie-down is accomplished. The loadmaster will thoroughly inspect tie-downs and the health physicist will then, again, check the cask.

Obviously the loading procedure is merely reversed when the aircraft reaches its destination and the package is again transferred, most probably, to a trailer.

(c) Air transport

One unacquainted with the technical aspects of radiation and its effects upon various materials may wonder whether special precautions should not be taken with aircraft equipment when transporting an item which emits ionizing radiation, in any amount. Most reasonably well-informed people will readily recognize that aircraft structural materials will be unaffected by the radiation emanating from a spent fuel element cask. Aluminum is a very stable material even in high radiation fields, and in such low radiation fields it is completely unaffected. The same may be said for stainless steel and other such metals as may be present in an aircraft cargo hold.

Organic electrical insulation has been known to deteriorate in high gamma fields but the threshold is usually mentioned as being around  $10^9$  rads which is a factor of  $5 \times 10^8$  higher than any possible dose aircraft cabling could receive during an eight-hour flight.

Still there are those uninformed people who might express doubt as to the radiation's effect upon aircraft instruments. The captains of some trans-Atlantic ships have, in the past, refused to carry parcels of medical radium aboard because of their unfounded but firm conviction that it would "put out their gyro." Because the principle of operation of any navigation instrument does not depend, in any way, upon ionization, these instruments are completely inert to gamma rays and neutrons at available intensities.

Actually, a great many gyrocompasses and other navigation instruments are equipped with pointers and numerals painted with self-luminous radium paint. The radiation produced internally by the instrument itself is often enormously greater than the additional radiation which could be produced at the instrument location by radioactive parcels in the cargo. Of course, neither the internal nor the external source of radiation affects the instrument in the slightest.

It is a commonly known fact that the performance of transistorized electronic equipment is degraded at lower radiation levels than that of electron tube devices. Such degradation becomes appreciable with integrated doses in the neighborhood of  $10^4$  to  $10^6$  rads (carbon) at high flux levels. No degradation at all will occur under the conditions involved in air-transporting irradiated fuel. Indeed the radiation levels induced by normal aircraft instrumentation, in the cockpit, are higher than those which would result from the presence of a spent fuel cask in the cargo hold.

Many navigation instruments contain 5 micrograms or more of radium, each. Gamma radiation, measured in the cockpits of empty DC-3 and DC-6 aircraft, due to radium paint on the instruments, has been found to give 10 mr/hr at the gyro and generally over the entire surface of the instrument panel, 5 mr/hr at the pilot's ankles, and 1 mr/hr at the back of the pilot's seat. Similar measurements have been made in the Constellation

aircraft of British Overseas Airways Company (BOAC) of values on the order of 0.1 to 0.2 mr/hr at the seat level and head of the pilot, copilot, and engineer. When aircraft are used as flying laboratories for the measurement of cosmic rays at high altitudes, it is customary for the standard instruments to be replaced with duplicates which do not have radium-painted dials. Otherwise, the normal navigation instruments would emit so much gamma radiation that the cosmic ray detectors, which do operate on the basis of ionization produced, would be inoperable or would give false readings.<sup>8</sup>

There is no known flight instrument, navigation instrument, radio, radar, or television apparatus which is responsive to the gamma-ray intensities to be encountered in the shipment of irradiated reactor fuel elements. Thus the hazard of radiation to aircraft instruments is a nonexistent and imaginary problem.

## (2) New reactor fuel

The transport of new reactor fuel is rated as the second most potentially hazardous operation involved in the air logistic support of a military nuclear power plant, the first being the airlift of irradiated fuel. Actually the difference in situations is striking when one realizes that the exposure of personnel to ionizing radiation, granted that it is at a very low level, is inevitable in the transport of irradiated fuel, whereas such is not the case with new fuel. Many scientists feel that any addition made to the radiation doses human beings receive from natural sources is undesirable. The danger of inadvertent criticality with new reactor fuel can be controlled to a very high degree of assurance with proper container design as may be seen in section 5. a. (2) of this report and the loading and normal flight procedures are very much like those one would anticipate with any other moderately bulky item of cargo.

Shipping and receiving personnel do have some rather important functions to perform, however. The first of these is the insertion of poison plates or strips into the fuel element array, if such are required to meet the nucleonics criterion. Next, any fixtures required to hold neutron absorbing control rods or poison in place and to ensure the integrity of the fuel element and poison assembly will be properly installed. The container loading will

then be made, if the preceding operations were not already conducted in the container. The gasket on the lid would be replaced, provided that it has not been previously taken care of, and the lid would be mounted and bolted in place. If it is desirable to keep the fuel elements in a pressurized environment of inert gas during shipment, for the purpose of keeping them clean and dry, the container would then be pressurized, using the appropriate valves provided in the containing design for this purpose.

The closure seal and lock will then be applied and the container properly marked. The aircraft loading will not be discussed in any detail as there is nothing unique about the operation. The package, at the most, will weigh a few thousand pounds and is easily loaded, tied down, and unloaded under the direction of any qualified loadmaster.

The flight plan, as approved through the organizational channels discussed in section 3, will undoubtedly call for the exclusion of all other fissionable materials, neutron sources, and neutron-reflecting or moderating materials such as beryllium, graphite, or heavy water, or explosive or flammable material, from the cargo. As specified in 10 CFR 71, it may be expected that all other materials which will occupy the cargo hold of the aircraft with the reactor fuel, will be listed in the request for approval of the shipping plan.

The exclusion of certain materials from the near proximity of the fuel element package obviously calls for the informal establishment of certain security measures by the aircraft commander. Security measures are also dictated by the value of the cargo. A core for a 10-megawatt (thermal) remote military plant may contain up to a half a million dollars worth of enriched uranium. Also, the hazard generated upon the opening of the package by some ignorant person is a consideration. Such contingencies can be precluded by the simplest security precautions, such as the placing of the aircraft under guard when making refueling or overnight layovers to prevent unauthorized personnel from gaining access to the cargo.

The aircrew's exposure to ionizing radiation emanating from the package and radioactive contamination will be nil and, therefore, it will not be necessary for them to be members of a health physics program; i. e.,

they need not have documented radiation-exposure histories, carry film badges or dosimeters, or have their loading and other operations monitored by a health physicist with radiation survey instruments. A properly briefed aircrew is well qualified to enforce all the required safety measures and completely eliminate the chance of exposure to any finite radiation level.

(3) Radioactive wastes

Liquid radioactive waste, in the form of a sludge, will be drawn off of the decontamination system of a military nuclear power plant, on a batch basis as determined by factors such as tank capacities and plant health physics procedures. This will be done by plant personnel under the supervision of an appointed, qualified health physicist in an area specified for this operation.

This area must be secure and well ventilated. In all probability adequate health physics procedures will call for the wearing, by all personnel involved in the transfer operation, of face masks or self-contained breathing apparatus, protective clothing and booties, and gloves to prevent contamination being ingested into the body via the hand-to-mouth route or through cuts. Direct radiation levels will be continuously monitored by the health physicist in charge.

Prior to the filling operation the outside surface of the containers, if they are reusable containers which have carried waste before or have been stored in a designated radiation area, should be surveyed for contamination levels. If the surfaces are above tolerable limits suggested as 4,000 disintegrations/minute/100 square centimeters of beta-gamma activity or 500 disintegrations/minute/100 square centimeters as determined by a finger wipe test, the cask should be decontaminated. Procedures for the decontamination of mechanical items will not be discussed here as they have been detailed in section 2. a. (4) which deals with the decontamination of radioactive tools and components.

Also, at this time an inspection of the mechanical integrity of the cask and the mating of its closure surfaces should be checked.

Next, the filling operation is accomplished. If the waste is to be stabilized in solid form, which is desirable, and the container is to be reused, a layer of parting agent should be applied. In most cases the container will be disposable because of the low level of activity of the waste, and this

operation will be unnecessary. Great care should be taken in the filling operation to prevent splashing or spilling of the sludge. Sufficient room should be left for the stabilizing agent which now should be added. Obviously, thorough mixing of the cement or other stabilizing agent should now be made. A constant survey of the radiation level will be made during the filling and stabilizing operation.

The container will now be sealed. If the seal is to be made by bolting, a gasketed closure will be used. If, on the other hand, the closure is to be made by welding, which is desirable for disposable containers, a gasketed closure is not required, provided the weld is made continuously around the entire periphery of the closure and is of high quality.

A survey of the exterior radiation and surface contamination of each package should then be made. The criteria of 200 milliroentgens per hour on contact and 10 milliroentgens per hour at a distance of 3 meters (for an aircraft of which the package has exclusive use) should be exceeded only in situations of high military necessity. Next, the package should be labeled; it is then ready for shipment.

The destination may be a designated spot in the deep ocean or, more probably, a disposal site in the continental United States. Burial sites are located at the Hanford Works, Richland, Washington; the National Reactor Testing Station, Idaho; Los Alamos Scientific Laboratory, New Mexico, Oak Ridge National Laboratory, Tennessee; and the Savannah River Works, South Carolina. The Air Force Logistics Command (San Antonio Air Materiel Area) currently has a contract for the disposal of such material at sites in Kentucky and Nevada with Nuclear Engineering Company, Inc., of Walnut Creek, California. These areas have been selected on the basis of several criteria aimed at reducing environmental hazards below tolerance levels, at the same time permitting constant surveillance and forbidding the use of the land by the public for generations to come. While it is difficult to generalize on the time required for waste to decay down to harmless levels, storage periods of 500 years are often mentioned for untreated waste and 10 to 15 years for waste from which the long-lived isotopes of cesium and strontium have been removed.

The shipment of waste should not require escort by a health physicist if the waste is in a stabilized form. A properly briefed loadmaster and aircrew are fully capable of taking any required measures. Prime considerations are the avoidance of the near proximity to the package and proper tie-down. Particular logistic conditions may make it desirable to dump the wastes from the aircraft directly into the deep ocean. If such is the case, the aircraft must be properly equipped, and the package must be properly rigged for jettisoning. General information on equipment and procedures for this operation is available in the dash 9 technical order for the particular aircraft in question. Unless the waste is of very high activity, and such material is not likely or considered here, the establishment of a health physics program will not be required. Caution should be taken not to place photographic film near the shipment as it may be fogged. Emergency procedures for these radioactive waste shipments are discussed in section 5. c. (3).

At the ultimate destination, the inside of the shipping container must be decontaminated if the container is to be used again. The criteria are the same as before. No special precautions whatsoever need be taken in returning this container to the plant site, if these criteria are met.

The only possible accident that could occur would be the spillage of unstabilized liquid waste from a damaged container. The aircrew should be instructed to avoid the areas which have been in contact with leakage, even after it has dried up. Cleanup should be attempted only by health physics personnel, but the requirement is not urgent provided all personnel can be kept out of the area. As mentioned previously, however, it is highly recommended that liquid waste be stabilized with cement or some similar material so that such an occurrence is impossible.

#### (4) Contaminated components and tools

Actions which must be taken by health physics personnel to decontaminate components or tools will not be discussed in detail. Illustrations of such methods are given in section 2. a. (4). The many techniques for decontaminating such items are well known to any trained health physicist.

In general, no special precautions need to be taken with such items, provided their contamination levels are low enough to be accepted for

such shipment. Care should be taken, of course, to ensure that the packaging, whose primary purpose is to prevent direct handling of the item by uninformed personnel, is not breached.

Other items of equipment may be carried in the aircraft with the contaminated component or tools; however, it is desirable that the maximum distance be maintained between the contaminated item and any photographic film.

(5) Aerospace reactor systems

It is highly doubtful that any responsible agency would ever attempt to ship a space reactor system by air without qualified escort. Not only is there an expensive loading of uranium in the fuel elements, but more importantly, an item such as an early SNAP 10A or SNAP 50-SPUR is the culmination of many millions of dollars worth of research and development activity and is certainly very valuable as well as potentially dangerous. While on the aircraft, of course, the aircraft commander has the final word; the escort, however, may certainly advise him. This escort need not be a health physicist. The effective absence of ionizing radiation from the packages makes the institution of a health physics program, the wearing of personal film badges and dosimeters, and the surveillance of the different loading and unloading operations unnecessary.

Here again, it is most difficult to generalize to any extent upon normal flight and loading procedures as such procedures will be quite dependent upon the particular nature of the equipment in question. One can do little more than review the terrestrial operations planned for the SNAP 10A, the only aerospace reactor system to reach final hardware stage, at this writing, and stress those points which might seem common to space reactor systems to be developed in the near future.

Figure 19 shows the SNAP 10A auxiliary power unit (APU) being lowered into the bottom half of its shipping container at the contractor's facility. A cradle, isolated from the trailer bed by shock absorbers, is ready to receive the APU.

Before this, the reflector assembly surrounding the fuel element canister has been removed and replaced with a sleeve of low neutron reflectivity (see figure 20 for a picture of the reflector plates and control drum in place

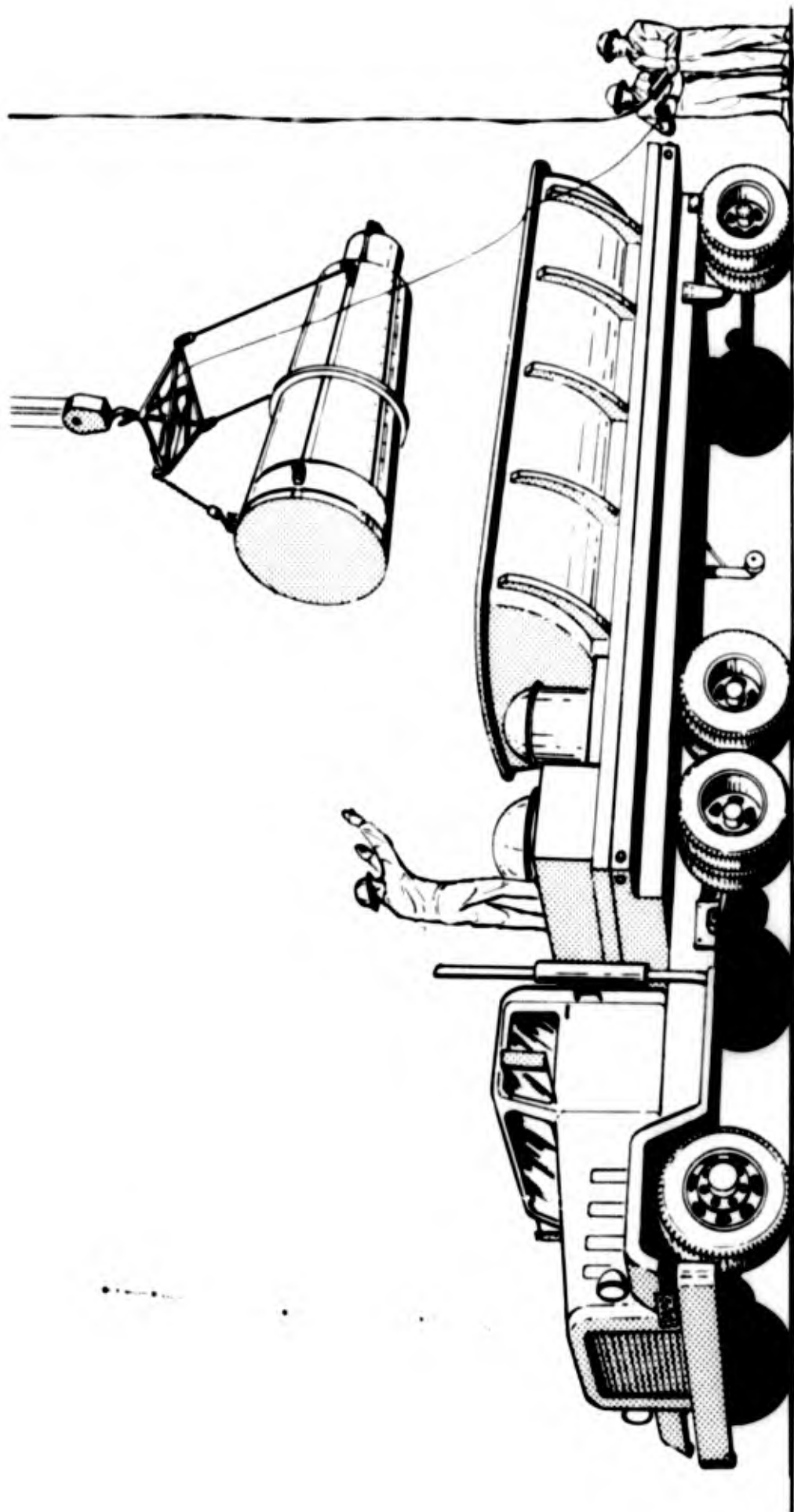


Figure 19. SNAP 10A - APU shipping container loading

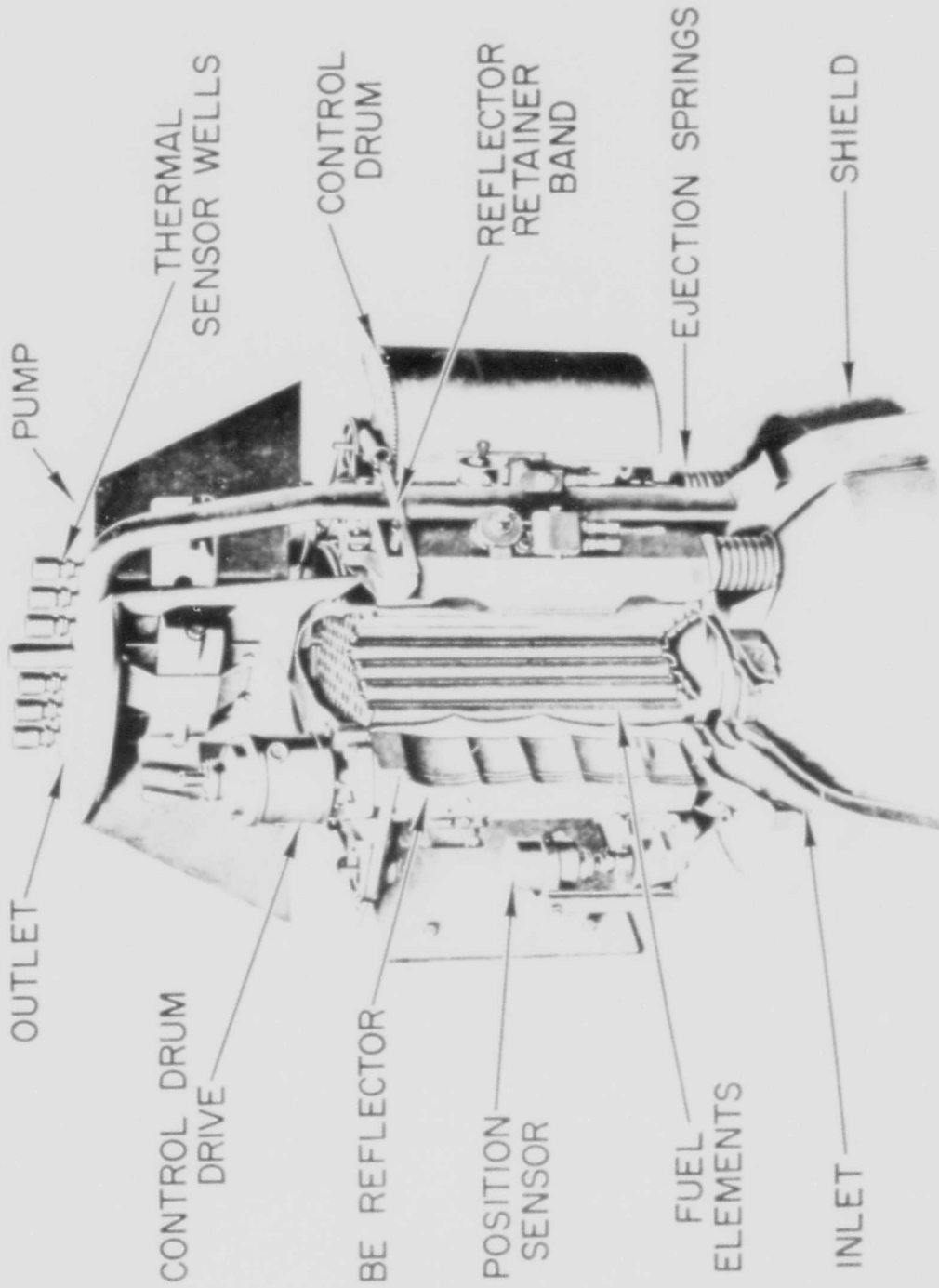


Figure 20. SNAP 10A reactor

around the fuel element canister).

Any other mechanical interlocks, safing devices, etc., would be activated at this time. The container has also previously been pressure-leak-tested to determine conformance with specifications.

If a neutron source is to be included in the package to provide neutron detectors with an adequate background against which to detect rises in the neutron population, it should be installed at this time. The neutron source will be a low level source and while direct exposure to it at close distances for prolonged periods of time will be discouraged, the exclusion distance provided by the physical dimensions of the APU package will result in a negligible dose to the aircrew during transport.

The next function would probably be the final calibration of the instrumentation, if required by any of the sensors. The container could then be "buttoned up," purged of atmospheric air, and pressurized to a few psig with an inert gas (in the case of the SNAP 10A, argon). The package would then be ready for shipment.

While the APU will be relatively light in weight (the SNAP 10A weighs approximately 525 pounds), the container with all its shock mounting hardware, instrumentation, batteries, inert gas supply, and bulk will probably weigh several thousand pounds. This should present no unusual problems for a qualified loadmaster, however. If planning for transport is properly executed, the height of the bed of the trailer bringing the container to the aircraft will closely match the floor elevation of the aircraft. The container will most likely be mounted upon skids or palletized in conformance with the 463L Materials Handling System and loading will be made with the usual portable winch and pulley type of arrangement. The tie-down operation would follow.

Normal flight procedures will call for a periodic check of the package instrumentation. Of course, any other material which can nominally be designated as fissionable, neutron moderating, or neutron reflecting, must be excluded from the aircraft cargo compartment, and this calls for the practice of a little security on the part of the aircrew.

If this shipment is made as described in section 5. a. (5) it is

actually impossible for a critical assembly to be made because material sufficient for the formation of the critical mass will not be present.

Likewise, the leakage of NaK or other coolant from the APU is very unlikely as the unit is extremely rugged; it must be, to be capable of being launched into space. Vibrational and environmental testing performed upon the unit to ensure its compatibility with the booster vehicle will undoubtedly far exceed any specifications imposed upon the unit to ensure safe air transport.

Nonetheless, periodic monitoring of the internal pressure, internal temperature, and neutron multiplication channels should be performed by the APU escort. The shock and vibration information gathered will have more of a documentary rather than an immediate utility and these forces need not be closely monitored during transport. This information would be desirable only when the APU is exposed to unusually severe shock or vibration and when it is desirable to know the shock and vibration the unit is exposed to before testing to determine the extent of any possible damage.

In normal flight it is highly unlikely that the APU will ever be flown outside the continental United States. As the package weight will not be a significant portion of the capacity of most transport aircraft in the Air Force inventory, it should be possible to perform the airlift operation in one hop. This will eliminate the need for special security precautions at intermediate layovers and further simplify the airlift operation.

In summary then, the only unusual demand made of the aircrew is that they ensure the exclusion of certain materials from the proximity of the nuclear APU package. The escort will maintain surveillance of the package and advise the aircraft commander in the event of an unusual occurrence with the package.

#### (6) Radioisotope generators

Of all the shipments of radioactive material which could be made via USAF aircraft, radioisotope generators must come very close to being those posing the lowest possible hazard. This is due to the inherently high structural integrity of such power units. The low level of the hazard involved calls for hardly any special precautions during loading, unloading and normal flight.

The establishment of a health physics program will be unnecessary in most cases. RTGs using alpha-emitting sources will most certainly not require any kind of health physics program. On the other hand, large beta emitters such as the SNAP 17, whose associated radiation levels may approach the 200 mr/hr on contact and 10 mr/hr at 1 meter criteria would necessitate documenting and controlling the exposures that aircrews and loading personnel receive.

Security may vary with the individual unit also. Some units intended for classified applications may have to be carefully guarded. Even if one neglects the application of the unit, however, radioisotope material is valuable in itself and this should require certain "common-sense variety" precautions.

None of these radioisotope generators, provided they are unclassified in themselves, should require an escort. Even with large  $\text{Sr}^{90}$  units, a well-briefed and competent aircrew should be capable of handling any situation safely without unduly exposing themselves.

Before releasing the package for shipment, the contractor should conduct a final inspection and survey. Both direct radiation and surface contamination should be measured. Exterior temperatures should be checked and a visual inspection of the generator unit and package should be made.

Once the package is accepted, the loading operation should be very simple. The package may weigh a few hundred pounds at most and should be easily handled. Personnel exposure to the package should, of course, be minimized. The package should be placed in a relatively open area where cooling air may freely circulate around it. As the package will be rather small, other cargo or personnel may be carried in the aircraft with it. As much separation as possible should be maintained between passengers, other cargo, and the unit. No photographic film should be carried unless absolutely necessary or unless the radioisotope fuel can be classified as a pure alpha emitter.

These are the only precautions which should have to be taken in the normal transport of a radioisotope generator system.

c. Emergency and accident procedure standards

Throughout this report strong emphasis has been placed upon the theme of maximum dependence upon equipment for safety and minimum dependence upon correct operational procedures and, thus, upon personnel. This section deals with the situations in which happenings of extremely low probability occur, namely, accidents. Those accidents whose occurrence has been deemed incredible because of the mechanical design criteria the package or power unit must meet, will not be discussed here.

(1) Spent reactor fuel elements

(a) In-flight trouble

Four varieties of in-flight trouble have been deemed credible, though highly unlikely, in the airlift of irradiated reactor fuel elements. They are the following:

1. Aircraft engine failure

The occurrence of an engine failure or some other malfunction which would prevent the aircraft from reaching a point at which a safe landing could be made might make it desirable to lighten the aircraft and thus increase its range. For this reason, it has been suggested that the cask and pallet be designed and installed in the aircraft so that they may be jettisoned and parachuted to earth if need be.

Parachutes have been developed to the point where they are very reliable devices. In any conceivable instance, it would be preferable to eject an irradiated fuel element cask and let it fall to earth beneath a deployed parachute rather than retain the package within the aircraft when it crashes. The shock the package will receive in being parachuted to earth will undoubtedly be much less than any it would receive in a crash and the probability that fuel elements and even cask coolant will be retained is much higher. Even though the recoverable uranium in the fuel elements is very valuable, it would be preferable to eject the package over deep water from which it could not be recovered, as this would completely preclude the possibility that someone could tamper with a cask and receive a massive radiation dose or unwittingly make a critical assembly. While it is hoped that the

marking on the package would discourage such tampering, the labels should not be relied upon to any great extent. In such circumstances, it is more desirable to render the package unavailable to all human tampering, forevermore.

The responsibility for the decision as to whether to eject or not lies with the aircraft commander. He must be familiar with the details of his cargo, in this instance to a much higher degree than usual, and should realize that, if he does eject the package and it cannot be recovered, he is literally throwing away up to a half million dollars worth of uranium. Of course, if ejecting the cargo means saving human lives and the aircraft, he has no choice.

The details of rigging a package for ejection and jettisoning it will not be delved into here. They are adequately spelled out in the dash 9 technical order for aircraft in question. A careful record should be kept by the navigator of the position at which the package is jettisoned.

## 2 Loss of cabin pressurization and heat

All of the aircraft considered eligible for the airlift of irradiated reactor fuel are of the turbo-prop (C-130, C-133) or turbojet (C-135, C-141) variety with optimum cruising altitudes in excess of 25,000 feet. To fly at these altitudes cockpits and cabins must be pressurized. With jet aircraft power plants, this is done by bleeding high-pressure air from one of the compressor stages, running it through an air conditioner to lower its temperature, and finally ducting it into the cabin. The heat energy stored in the air in the turbine compressor, which is not removed in the air conditioner, is used to heat the cabin. One must remember that, at 30,000 feet, a common cruising altitude for such aircraft, the ambient pressure is in the neighborhood of 4.5 psia (sea level is 14.7 psia) and the ambient temperature lies between  $-10^{\circ}$  and  $-85^{\circ}$  Fahrenheit.

With the onset of an emergency in which cabin pressurization and heat are suddenly lost, as might occur with the loss of a door, one may ask how the irradiated fuel element cask will be affected. The effect of the loss of pressurization will be to increase the pressure differential across the cask wall by 10 psi. The AEC minimum pressure specs (10 CFR 72)

have been upped 10 psia, however, in the proposed container criteria, to cover just such a contingency, and so this rapid addition of 10-psi pressure differential across the cask wall should not affect the package at all.

If, however, the cask is exposed to such low ambient temperature (ARDC 1959 Model Atmosphere gives a temperature of approximately  $-50^{\circ}\text{F}$  for 30,000 feet) for prolonged periods of time, the coolant may freeze, greatly impairing the heat transfer mechanism by which the cask dissipates the heat generated in the radioactive decay of the fission products. Fortunately, the cask will not be exposed to such temperatures for very long and, as the cask has tremendous thermal mass, it would take many hours of exposure to such temperatures before the coolant (even without antifreeze) would begin to freeze. An aircrew, at say 30,000 feet, which loses cabin pressurization and heat finds themselves suddenly rather uncomfortable. Besides becoming very cold very quickly, the inside windows have a tendency to frost up and the aircrew members must go on oxygen to prevent passing out. With or without the cargo, the procedure for the pilot would be to immediately drop down well below 20,000 feet, descending at a rate of probably somewhere around 4,000 feet per minute.

The loss of cabin pressurization and heat, then, will not affect the irradiated fuel cargo if normal operational procedures are followed.

### 3 Loss of internal cask pressurization

During flight there is some small possibility that internal cask pressurization, applied as part of the container design to enhance the overall heat transfer mechanism, may be lost as a result of gasket or valve failure. One may see, by examining paragraph 4.1.2.4 of the proposed container criteria, that the cask coolant will not be expected to boil. Nonetheless, it would be good policy to increase cabin pressure as much as possible because the temperature at which the coolant will boil will increase with increasing pressure.

The loss of pressurization will also result in the release of gas from the inside of the cask. If the coolant has met the specifications of paragraph 5.14 of the criteria, as it must for the cask to be released for transport, this gas should not be unduly contaminated. In spite of this, the

filter as specified in paragraph 5.7 of the proposed criteria will entrap practically all solid contamination which could be released through the pressure relief valve. In almost every case the gas will be released through the pressure relief valve.

In any case in which the depressurization of the cask is noted, the pilot should employ whatever methods are available to him to increase the rate of air circulation in the cargo compartment. Also, it would be wise for the entire aircrew to draw their breathing air from the aircraft oxygen system or walk-around bottles, for the remainder of the flight, as an added precaution against the possibility that radioactive iodine and other gases have escaped.

Upon landing, the aircraft should be quarantined and the aircraft commander should immediately contact the base commander and request the services of the base disaster control team. This team would then, under the direction of the health physicist escort, survey the aircraft for decontamination and decontaminate the plane as necessary.

#### 4 Cask coolant leakage

In spite of the fact that all valves must be checked under pressure and locked shut prior to shipment, there is a minute possibility that leakage of the cask coolant could occur. Certainly this leakage would be small as a complete valve failure is practically impossible and the cask will be inspected frequently by the health physicist escort. He should notice the leakage before a considerable amount has escaped and tighten whichever valve is leaking. The question of the activity of the leakage now arises.

The health physicist escort should have an alpha survey meter such as a PAC-1S and a beta-gamma radiacmeter such as the AN/PDR-27 aboard the aircraft. With these he can perform a wipe test, after he has wiped up as much leakage as possible and the remainder has dried, and determine whether any residual contamination remains. If it does not, the leakage may be neglected. If he determines that the leakage is unacceptably contaminating the aircraft he would then (1) prevent further spread of the contamination by blotting up the leakage, (2) mask off the contaminated area and declare it off-

limits to the rest of the aircrew, and (3) upon landing, obtain equipment and assistance necessary to decontaminate the aircraft and accomplish same.

The escort should attempt to determine how much water has leaked from the cask and figure out what portion of the fuel elements have been uncovered. Hopefully, the active area would still be submerged. Even if it were not, however, no attempt should be made to refill the cask as the thermal shock the elements would receive would probably do more harm than allowing them to stand only partially submerged in water. The leakage of the coolant will necessarily imply a partial loss of cask internal pressurization. At the next opportunity, the escort should obtain a compressed air source and pressurize the cask to its original value. Upon arrival at the reprocessing plant, the escort should personally notify the supervisory personnel there of the leakage and of what portion of the fuel elements he estimates are uncovered.

The rags, sponges, or pieces of absorbent paper the health physicist uses to blot up the leakage should be carefully controlled, if it has been determined that the leakage was contaminated, until such time as he can see to it that they are properly disposed of as radioactive waste.

(b) Crash (Stateside)

If a crash of an aircraft carrying a shipment of irradiated reactor fuel is unavoidable, but foreseeable, and if sufficient time remains, the package should be jettisoned. The reasons for adopting this position have been discussed previously. The condition of the aircraft, the aircrew, the package, and the location of the point at which the ejection is made should be radioed to the nearest military or Federal Aviation Agency (FAA) control center. If ejecting the package means that the aircraft will then have sufficient range to make it to the next landing field, the pilot will obviously proceed. If, on the other hand, the aircraft must still be abandoned by its crew and will crash in some sparsely populated area, then such can be accomplished with the assurance that the maximum precautions have been taken to minimize the hazards associated with the radioactive package.

The final preparations for the ejection of such a package from an Air Force cargo plane of the C-130, C-133, C-135, C-141 variety take about ten minutes. In emergency situations in which crash of the aircraft

follows, such time is usually not available. Indeed, in a great number of military air crashes (and civilian for that matter, too) the planes just suddenly disappear without the receipt by any station of any word from them. In short, in the majority of air crashes, there is probably not sufficient time to jettison the package even though it may be properly rigged, and the package will crash with the aircraft.

**1 Missing aircraft**

The following sequence of events could be anticipated in the event that an Air Force cargo aircraft carrying a shipment of irradiated reactor fuel shows up as missing, somewhere within the boundaries of the continental United States.

**a** As specified in AFR 55-8, "Overdue Aircraft," the Federal Aviation Agency Control Center having the responsibility for operations in the area of the destination base listed on the DD Form 175, Aircraft Clearance form, will initiate a preliminary communications search for the aircraft when an arrival report has not been received within 1 hour after the estimated time of arrival or at the time of fuel exhaustion, whichever occurs first.

**b** If the preliminary communications search is unsuccessful, the FAA Control Center will classify the aircraft as overdue and notify the base of departure and the appropriate Air Rescue Center (Eastern ARC at Robins AFB, Georgia; Central ARC at Richards-Gebaur AFB, Missouri; and Western ARC at Hamilton AFB, California).

**c** The base of departure, as soon as it is notified that the aircraft carrying irradiated reactor fuel is overdue, should:

1) Alert the military installation nearest the expected crash point of the presence of the radioactive cargo aboard the missing aircraft and request that the installation commander place those elements of his disaster control team with radiological defense capabilities on an alert status.

2) Notify (by teletype) the Chief of Staff, Headquarters USAF, and the Directorate of Aerospace Safety, Deputy, the Inspector General, USAF, Norton AFB, California, giving names, grades, and service numbers of crew and passengers, type of aircraft, aircraft number, home base of

aircraft, home base of pilot, place and time of departure, intended destination, route, mission, estimated time en route, position when last reported, weather over route, an exact description of the cargo, and any other pertinent information.

3) Notify, by the most expeditious means of communications, the commander of each person aboard the aircraft and the home base of the aircraft, and submit progress reports in accordance with AFM 30-4.

d The Command Post at Hq USAF should contact the Joint Nuclear Accident Coordinating Center (JNACC) at the Albuquerque Operations Office of the USAEC (Area Code 505, phone number 264-4667), Albuquerque, New Mexico, informing it of the details of the missing aircraft and cargo and what radiological monitoring, recovery, and decontamination capabilities are on call for the time when the missing aircraft is found. This is exactly the same procedure as one finds in AFR 355-7, "Response to Accidents Involving Nuclear Weapons and Materials." The Hq USAF Command Post may also direct the Commander of the Base of Departure or the Military Installation expected to be nearest the scene of the crash to request additional radiological monitoring and decontamination assistance from the 2705th Airmunitions Wing, Hill AFB, Utah.

## 2 Known crash location

At such time as aircraft debris is located or in the case when the pilot has been able to call in the expected locations of the aircraft debris and cargo, the procedure will be as follows:

a The commander of the military installation nearest the scene should dispatch his radiological defense team to the point at which the irradiated fuel element cask has been found with orders to assess the degree of contamination, secure the area, and to conduct decontamination and recovery of radioactive material, within their capabilities.

The first team of personnel expected to reach the crash scene should be instructed as to the nature of the radiation hazard they should expect. They should be told to approach the scene from an upwind, and hopefully, uphill position and should wear gas masks or self-contained breathing apparatus. They should constantly monitor whatever instruments they have for

direct beta-gamma-type radiation, and also watch for deposited alpha contamination (from the fuel material). A thorough survey of the area should be made and contaminated areas posted. The initial prime concern is, of course, the humane one; if there are any survivors at the crash site which can be helped by the first team to reach them, then such action becomes paramount. When whatever can be done for survivors has been done, however, then the prime consideration should become the recovery of the radioactive and fissionable material and the decontamination of the crash site.

b The Commander of the Base of Departure should:

1) Notify Hq USAF with an APEX BEELINE report (reference AFR 55-130, "APEX BEELINE Report of a Serious Accident, Incident, or Disturbance").

2) Notify the Chief of Staff, et al., as per paragraph c of this section.

3) Notify the commander of each person aboard the aircraft and the home base of the aircraft as per AFR 55-8 and AFM 30-4.

c The Hq USAF Command Post should keep JNACC up to date on the status of the accident and what capabilities are being brought to bear on the problems of contamination assessment, decontamination, and recovery of radioactive material. If further capabilities are required, they should be requested by Hq USAF from JNACC upon the advisement of the authority in charge of the accident on the scene, usually the team commander dispatched from the nearest military installation. With nuclear weapons, an agreement exists between the Department of Defense and the USAEC wherein the immediate responsibility for providing technical direction at the scene of the accident will be assumed by the service or agency receiving first notification of the incident, whereas the primary and continuing responsibility for providing technical direction at the scene of the accident will be assumed by the service or AEC agency having physical possession of the item at the time of the accident. As one can see, then, while another military service or even AEC agency or contractor may initially take charge at the scene of the accident, the Air Force will ultimately have the primary and continuing responsibility for providing technical direction, if like reasoning applies, as it

should. The Air Force may well require assistance, however, and for these requests the Hq USAF-JNACC channel should be utilized.

d Air Force responsibilities will terminate only at such time as the crash scene has been adequately decontaminated or placed under permanent control and the accident has been thoroughly and completely investigated. The USAF Chief of Staff will undoubtedly charge the Inspector General with these responsibilities.

(c) Crash (Overseas)

The philosophy concerning the ejection of cargo over friendly foreign territory will probably differ from that which will prevail concerning flight of such material over the continental United States. The ditching of any such material in the international waters of the deep ocean will probably be acceptable no matter whose territory those international waters happen to be close to. On the other hand, it may well prove to be undesirable to jettison a package of irradiated reactor fuel over foreign territory and it may actually be desirable to have the aircraft crash with the cask aboard, even though the chances of damage to the cask and contents would be greater, because of the lesser political implications of controlling one accident on foreign terrain as opposed to controlling what might appear to be two accidents. This matter cannot be generalized upon because of the differing political implications. A clarification of this matter should be obtained when applying for overall approval of operational plans which include flight over foreign territory, as discussed in section 6.

In foreign countries, United States air traffic is controlled by the local air traffic control agency. In the case of a missing or overdue aircraft, that agency will make a communications search and report the missing or overdue aircraft to the destination base in much the same fashion as the FAA does, within the United States. AFR 55-8 charges overseas major air commanders with the responsibility for publishing supplements to AFR 55-8 outlining procedures to be followed for overdue aircraft in their areas. In general, these will be similar to those briefly discussed in the section preceding this which dealt with overdue aircraft in the continental United States. The specific directives published by the theatre commander should be consulted when planning any such flight in an overseas area; however procedures

following a crash may be expected to closely resemble those described for a stateside crash.

One exception to this, however, will be the sources of radiological monitoring and decontamination personnel overseas. The United States Air Force, Europe, has its own organization, the 7410th Explosive Ordnance Disposal Squadron which its commander will dispatch to the scene of an accident occurring in its areas. Likewise, a similar organization, whose office symbol is (PFMSS-W), exists for the Pacific Air Forces. The 2705th Air Munitions Wing at Hill AFB, Utah, has the responsibility for the continental United States (as mentioned previously) and Alaska, as well as responsibility for providing backup and technical advice to the 7410th E. O. D. Squadron, the Pacific Air Forces, and to Canadian explosive ordnance disposal organizations.

The responsibility of the commander of the U. S. military installation nearest the scene of the accident to alert and dispatch his radiological disaster control team and the responsibility of the commander of the base of departure to alert the base nearest the anticipated or actual scene of the accident, to notify the commanders of the personnel concerned, to file APEX BEELINE reports, and to alert the Chief of Staff, USAF, and the Directorate of Aerospace Safety, Deputy, the Inspector General, USAF, at Norton AFB, California, will undoubtedly remain unchanged. Either the commander of the base of departure or the commander of the military installation nearest the scene of the accident will be responsible for keeping the theatre command post continually informed as to the status of the accident. The theatre command post, however, should be charged with the responsibility for ensuring that all proper resources are brought to bear on the problem of monitoring and decontaminating the accident area since it will be apprised of the personnel and equipment in its area and since the USAF Command Post and JNACC are simply too far away. Of course, the theatre command post will report directly to the USAF Command Post concerning the status of the accident and forward any requests it may have to submit for additional assistance to the USAF Command Post.

(2) New reactor fuel

(a) In-flight trouble

The statement may be safely made that, when the other

provisions discussed in this report concerning the airlift of new reactor fuel elements are in force, there are absolutely no operations that the members of the aircrew could be called upon to perform upon the package in flight.

The container in which the new reactor fuel is shipped will contain no coolant which could leak out and contaminate the surroundings. There is no finite level of ionizing radiation emanating from the package.

In no case could a critical assembly be made. The poisons required to "hold down" the assembly are firmly held in place and will not leave their required positions even when subjected to a temperature of 1300°F. The contents will remain satisfactorily subcritical even when the package is dropped 30 feet onto a concrete surface. A  $k_{eff}$  less than 0.8 will prevail even when the package is submerged in water and water leaks inside the container. Neutron moderating and reflecting materials have been barred from the near proximity of the shipment. In short, in no circumstance short of a major air crash will a package of new reactor fuel ever require any attention on the part of the aircrew.

Regarding the situation in which a crash or ditching of the aircraft seems imminent, the question of jettisoning the cargo again comes up. From the standpoint of allowing the aircraft to reach a landfall, the weight penalty imposed by the new fuel element package is of negligible or, at the most, of marginal importance. Such a package will weigh a few thousand pounds at most, and, more likely, several hundred pounds. The installations necessary to jettison this item, i. e., the floor racks and other hardware, will quite possibly weigh more than the package and they would be considerably more difficult to discard from the aircraft in an emergency situation.

One may inquire as to the danger of criticality upon impact, in an air crash. Again, upon reading the container criteria in section 5. a. (2) it may be seen that the fuel assembly, even with a 10 percent reduction in volume, and after being subjected to 1300°F for 10 minutes, cannot have a  $k_{eff}$  greater than 0.8 even after being submerged in water. Add to this the fact that, while pessimists assume that accidents such as air crashes tend to concentrate fissile materials, anyone experienced in air rescue will testify that, in fact, they are actually highly dispersive in nature. Contamination of

the crash site from the release of fuel material is highly unlikely with stainless steel or refractory metal fuel elements. Such elements would have to be subjected to a very severe heat pulse to melt the elements down and the availability of such a source is very unlikely. Criticality would disperse fuel material and some fission products but, again, this is very unlikely even with the most severe crash. In short, the chance of a criticality upon impact or the contamination of the crash site by fuel material is so small, because of the equipment design, that it is not necessary or even desirable to attempt ejecting the package and parachuting it to earth from an aircraft experiencing an emergency.

Poindexter<sup>13</sup> offered a design for a new fuel element canister which he stated could be airdropped, via parachute, to a remote nuclear power plant site. While interesting, this provision seems at the least, to be somewhat visionary, as it is impossible to imagine any conditions wherein the need would arise for supplying reactor fuel to a power plant by means of airdrop.

The aircrew, then, once it has loaded and properly tied down the package and ensured that those materials classified as neutron moderators or reflectors are not in close proximity to the package, may regard the package as harmless.

#### (b) Crash

The only emergency situation which need be discussed with this type of shipment is then the crash of the aircraft. Procedures to be followed for overdue aircraft and the individual responsibilities of the various organizations regarding the accident will be just as discussed for irradiated fuel elements and will not be repeated here. The only difference is obviously, in the descriptions of the cargo which should be dispatched. The first team reaching the site of the aircraft, be it the radiological defense team from the nearest military installation, members of the 2705th Air Munitions Wing, the Pacific Air Force (PFMSS-W), or the 7410th Explosive Ordnance Disposal Squadron, should be instructed as to the possible presence of fissionable fuel material and low-level fission products as well. They should be told to approach the crash site from upwind and uphill, if possible, wearing gas masks or self-contained breathing apparatus, and should be told to make a thorough

survey of the area for alpha-emitting as well as beta-gamma contamination. Of course, the prime concern should be for the saving of human life; but if there are no survivors at the crash scene or if they do not require first-aid assistance, the prime concern should then be the recovery of the fuel element package.

The recovery of the reactor fuel material should not be attempted without the supervision of someone intimately acquainted with the design details of the fuel elements. It will be his responsibility to ensure that pieces containing fissionable material are identified and adequately separated or stored in containers made of neutron-absorbing materials.

The operations to follow, the reporting procedures, and the delineation of responsibilities will be just as discussed in the previous section, for irradiated fuel elements.

### (3) Radioactive wastes

#### (a) In-flight trouble

It has been highly recommended, previously in this report, that all radioactive waste to be shipped from a remote military nuclear power plant be in stabilized form prior to shipment. The mixing of liquid wastes with cement and the imbedding of small items of solid waste in the mixture before it sets are especially desirable. If these simple precautions are taken, there are no in-flight emergencies that could arise with the cargo short of an imminent crash of the aircraft.

If, on the other hand, wastes are shipped in liquid or sludge form (the approval authority may well refuse to allow such an operation), there is always the possibility (though a low one) that leakage will occur through the welded or gasketed closure. It has not been recommended that air shipments of radioactive waste be accompanied by an escort because of the low level of the hazard involved. Should this leakage occur, then, a member of the aircrew should be made responsible for taking note of where the leakage extends to and for keeping the other members of the aircrew away from this area so that they would not contaminate themselves or other parts of the aircraft. Upon landing at their next base, the aircraft commander should request the assistance of the base radiological disaster control team in the decontamination of his aircraft

and in remedying the source of the leakage. At the risk of being redundant, however, the chances are very low that liquid or sludge will be air-transported and also very low that a cask of radioactive waste would leak; hence the chances of such an accident really occurring are practically nil.

(b) Crash

It should always be remembered that, at the present time, the wastes with which we are dealing are worthless in value. The only reason for flying them is to transport them from a site at which they cannot be disposed of to one at which they can. As these wastes are of no value, jettisoning them from an aircraft over the international waters of the deep ocean becomes even desirable. Radioactive wastes, in stabilized form, are presently dumped from ships into certain, deep areas of the ocean as well as buried at national disposal sites on land. Transporting these wastes (to the deep portions of the oceans) by plane is probably overly expensive when compared to doing so by ship, but this does point out the fact that jettisoning such cargo over deep ocean need not be prohibited. If it were ever thought to be desirable to dump radioactive wastes directly from an aircraft, no parachute would have to be used, and the only precaution that would have to be taken, once the predetermined spot had been reached, would be for the aircrew to make a thorough radar search of the area to ensure that there are no ships in the area which might be in a hazardous position when the cargo is dumped.

Normal dash 9 technical order procedures should be adequate references for rigging the package or packages. As they are not meant to be recovered, a mechanical ejection mechanism is preferable to a drogue chute, which cannot be recovered, for drawing the items out of the aircraft.

The reader should be able to appreciate that the questions of whether to rig out the packages for ejection from the aircraft and whether to rig them out with parachutes will be highly dependent upon the areas to be overflown, the sizes of the packages, the physical state of the wastes, and the activity of the wastes. In particular, the question of whether the packages should be rigged for ejection to lighten the aircraft in the case of an emergency cannot be decided in general. The weights of the packages and the areas to be overflown must be considered. In foreign overflight, for example, it may be

wise to never allow the ejection of radioactive wastes, even with full parachute rigging, because of the possible political implications. Clarification would have to be obtained on this matter as part of the application for approval for foreign overflight as per section 6 of this report.

Procedures for classifying, locating, monitoring and decontaminating the aircraft or its debris follow the same lines as those already laid down for crashes involving irradiated reactor fuel. Descriptions of the items of cargo will vary, of course. Dispatches should carry a description of the wastes to include their form, an estimate of the amount, and perhaps their source.

#### (4) Contaminated tools and components

The emergency and accident procedures dictated by contaminated tools and components are nonexistent. In almost all cases radiation emanating from these items will be undiscernible from that normally attributed to "background," and a radiation accident will be impossible.

Most generally, these items would be rather light in weight and the advantages to be accrued in ejecting them from an aircraft in distress will be minimal. Also, they would be fairly valuable, or they would not be shipped by air, so, if at all possible, possession of them should be maintained.

In the event of a crash, the rescue team first reaching and securing the site should be capable of identifying the radioactive items and placing them under adequate control. Messages exchanged between the base of departure and the military installation nearest the crash, between the latter and the theatre commander and those forwarded to Hq USAF and to organizations of the Inspector General, etc., should adequately describe the radioactive items aboard the aircraft.

It should be realized that precautions will vary with the nature of the equipment to be transported. For example, different procedures may be called for in airlifting a slightly contaminated pump and in airlifting the reactor pressure vessel of a military nuclear power plant that has operated at power for three years. On the whole, however, items falling in this category will have an associated hazard of such a low level and will be so far below

the aircraft's load carrying capacity in weight, that no special emergency or accident procedures will be in order beyond those covered in the foregoing discussion.

(5) Aerospace reactor systems

The packaging of aerospace reactor systems will be a highly individual affair. As there are no precedents for this type of operations, the packaging philosophy compiled for the SNAP 10A has been taken as being illustrative. It may safely be said that future aerospace reactor systems, because of their small size and their inherent ruggedness (required for the launch and space environments), lend themselves well to high-integrity packaging. The chances of the failure of such high-integrity packaging are small indeed.

(a) In-flight trouble

There are two failures which are remotely possible with a packaged aerospace reactor system and for which the aircrew should be prepared. The first of these failures would be the leakage of inert gas from the interior of the package. If one remembers that this gas was originally included to keep the package clean and free from the moisture in the air, it then becomes obvious that nothing very serious will result from the leakage of this gas alone. The escort would only make a notation of this failure of the package seal and inform the personnel at the receiving station of the leakage and the possibility of payload contamination.

A second more serious but much more improbable accident would be the leakage of liquid metal from the Rankin cycle loop of the auxiliary power unit (APU) due to vibration or shock encountered in flight. The SNAP 10A, as pointed out, uses a mixture of sodium and potassium (NaK) for its heat transfer fluid. While NaK does react, almost explosively, with oxygen and water, the reaction with gaseous oxygen is somewhat difficult to initiate at room temperature and really requires higher temperatures. The reaction with water is easily initiated, even at room temperatures. Future aerospace reactor systems, however, may use heat transfer fluids other than NaK, such as mercury, potassium (alone), and lithium, the latter two being considerably more reactive than NaK. As all such APUs will be contained in sealed packages

which are essentially pressure vessels, to protect personnel from such violent reactions with air or water, and are blanketed in an atmosphere of inert gas, there is no real hazard.

With the detection of the liquid metal leakage by the monitor instrumentation included in the container, the entire aircrew should be alerted, for, in the almost impossible event that liquid metal leaks from the APU and air leaks into the APU container, a fire may result which would release vapors of such toxicity as to necessitate abandoning the plane. (Alkali metal vapors are poisonous, not only when ingested, but also to exterior skin surfaces.) Also, of course, the presence of a high-temperature fire in the cabin of an aircraft could cause serious damage to the aircraft.

To be realistic again, the only event which could impart a shock violent enough to rupture the container and damage the APU to the point that it leaks liquid metal would be the incidence of a very severe air crash.

Criticality during flight is regarded as completely impossible. Neutron reflectors, used to control the reactor and bring it up to criticality, will be removed and shipped separately as will any neutron scatter shields designed to shield the rest of the payload. In the place of the reflectors, one will find neutron absorber sleeves, etc., whose attachment will be of such strength as to allow unplanned removal only by a deliberate, massive act of sabotage.

(b) Crash

The question of whether an attempt should be made to jettison the APU package upon the declaration of an aircraft emergency arises again. The APU itself will be comparatively light; the SNAP 10A weighs only 525 pounds. The container, however, being in effect a pressure vessel, may weigh several thousand pounds. It is hard to imagine any such package constituting more than a fraction of the load-carrying capacity of any of the aircraft in consideration. These packages should not constitute any severe weight penalty to these aircraft.

The prime consideration in determining whether these packages should be jettisoned or remain with the aircraft, come what may, will probably be security. In every case the reactor APUs will represent significant advances in many technologies such as high-temperature metallurgy, solid-state

physics, energy conversion, etc., and it may be desirable to classify certain design features, as was done with the SNAP 10A. Also, there is the possibility that someone, in attempting to disassemble the package which he has found, will generate a release of toxic chemical material or even a nuclear excursion which could become a considerable hazard to himself and to large segments of the populace. As it is highly unlikely that any great portion of the flight will be over deep water because of the high probability that all flights would be from one part of the continental U. S. to another, the chances that a package, jettisoned from an aircraft and parachuted to earth, would fall under the control of personnel ignorant of its potential hazard are finite.

It is, then, probable that plans for the air shipment of reactor APUs will not include plans to eject the cargo upon the incidence of a mid-air emergency.

The procedures for the identification and location of overdue aircraft in the United States, and for the proper notification of the various organizations upon the location of a crash that are spelled out in section 5. c. (1) for irradiated fuel, would apply here also. Messages dispatched from the base of departure to Hq USAF should contain an adequate description of the APU aboard the missing or crashed aircraft so that Hq USAF may relay this on to JNACC, if need be. Likewise, messages sent from the base of departure to the military installation nearest the crash site should contain not only a thorough description of the APU aboard the aircraft but a warning as to the possible presence of dispersed fission products, alpha-emitting fuel material, and chemically toxic materials (alkali metals, lithium hydride, and possibly beryllium with the SNAP 10A) in solid and vapor form. Personnel approaching the crash scene should be instructed to wear gas masks or self-contained breathing apparatus until it can be certified that the area is free from airborne contamination, and they should be careful not to enter any area which has not been surveyed for direct radiation or for radiological contamination. The saving of human life, as always, should be the paramount consideration. When this responsibility is discharged, the safe recovery of the APU or its debris should follow. This should not be attempted except under the supervision of someone from the APU contractor's organization or some other person

intimately associated with the design details of the APU, who can easily identify the various parts of the APU system and ensure the proper separation of those pieces containing fissionable material.

(6) Radioisotope generator units

It is deemed inconceivable that any in-flight emergency, caused by or affecting the cargo, could arise with the air transport of radioisotope generator units. The great structural integrity of these units, required for their launch into space and by the necessity for containing the fuel material upon exposure to the "maximum credible accident" which could occur during launch, discussed previously, renders them capable of easily withstanding any environment air transport could impose upon them.

These units are and will be extremely light and, as their packaging requirements are minimal, impose very little weight penalty upon a cargo plane. Jettisoning them in the case of a declared aircraft emergency would buy little in the way of additional range for the aircraft and only create an additional problem in trying to locate the package after the accident. It is recommended that the package remain with the aircraft during any emergency.

Missing and crashed aircraft procedures would not differ from those for a cargo plane carrying any other kind of innocuous cargo. Hq USAF should be notified of the presence of the item aboard the aircraft, however, in the event that an untrue and adverse press release is made. Every effort should be made to recover the item from the crash scene because of the cost of the fuel material and a person or persons capable of identifying the generator should be present during the clean-up.

d. Special air base, aircraft, and crew precautions

(1) Health physics program

Health physics is popularly defined as that branch of the radiological sciences dealing with the protection of personnel from the harmful effects of ionizing radiation. One may find from reading the preceding sections of this report that some element of health physics control should be exercised in all six categories of radioactive air shipments.

Health physics surveys for contamination of package surfaces will be mandatory prior to the shipment of irradiated fuel elements, radioactive wastes, and contaminated tools and components, and will, in all probability, be made prior to the shipment of new reactor fuel, space power reactor systems, and space power radioisotope generator units. The standard procedure is for the health physicist to rub a piece of clean, absorbent paper over a square of the surface in question, 10 cm on a side, and then measure the activity picked up. The criteria of acceptability for irradiated fuel element casks are readings less than 4,000 disintegrations/minute/100 cm<sup>2</sup> of beta-gamma activity and 500 disintegrations/minute/100 cm<sup>2</sup> of alpha activity. The paper sample should be dry to minimize the internal absorption of alpha particles. Most other general specifications for surface contamination levels give values of 0.3 milliroentgen/hour/100 cm<sup>2</sup> for beta-gamma activity and 150 disintegrations/minute/100 cm<sup>2</sup> for alpha activity as the maximum acceptable limits for the release of material to the general populace.

One might become confused over the differences in units in the specifications of acceptable beta-gamma activity made above. Actually, the units of disintegrations/minute/cm<sup>2</sup> are more meaningful from a scientific standpoint, than are the units milliroentgens/hour/cm<sup>2</sup>. Unfortunately, almost all field beta-gamma survey instruments, which are really designed to measure direct radiation rather than surface contamination, read out in terms of milliroentgens/hour (including the most common field instrument in the military inventory, the AN/PDR 27; see appendix IV). A calibration can easily be made of an instrument such as the AN/PDR 27 to convert readings of milliroentgens/unit time to beta disintegrations/unit time. The Biophysics Branch of the Air Force Weapons Laboratory (WLRB-3) is fully capable of performing such a calibration, for example.

As regards alpha surface contamination the units of disintegrations/unit time/unit area are especially appropriate because of the very limited range in air of alpha particles. The PAC-IS or AN/PDR-60, which is suggested for this use reads out directly in disintegrations (or counts)/minute (appendix IV).

At any rate, the initial health physics survey of a package presented for shipment, as described above, will be performed by a staff health

physicist from the agency or contractor presenting the package for air shipment, when appropriate.

Of the six different types of shipment discussed in this report, it has been recommended that two be shipped only under qualified escort. These two categories are irradiated reactor fuel and space reactor auxiliary power units. As it has been determined that the shipment of irradiated fuel contains the highest element of risk, what with the possibility of contaminated coolant leakage, the ever present ionizing radiation, and the difficulty involved in handling the heavy cask, it is the recommendation of this study that the person designated to accompany this package be a fully qualified and experienced health physicist. In all probability, this person will be a staff health physics technician from the nuclear power plant which is originating the shipment of irradiated fuel. It will be his duty to survey the cask, both with radiac instruments and visually, whenever any operations are performed upon or with it, and at periodic intervals during flight and storage. He will ensure compliance with those portions of the health physics program dealing with the proper wearing of film badges and dosimeters and the recording of dosimeter readings, recommend on-the-spot procedures which will result in minimum personnel radiation exposure to the loading and air crews, and at all times stand ready to advise the aircraft commander on any aspect of the shipment dealing with the package. The most probable (though not at all highly so) accident which could occur during air shipment would be the leakage of coolant from the cask. (Any more severe package failure could occur only under transport conditions in which it would be highly unlikely that any aircrew member would be operative.) In that instance, the health physicist escort would attempt to terminate the leakage, determine whether and to what extent contamination has been spread, control personnel access to the contaminated area, and advise the aircraft commander as to the behavior to be expected of the package (the ensuing rise in temperature, the possibility of radioactive gas leakage into the cabin, etc.), and the advisability of continuing the flight to the destination given in the flight plan. Obviously, this escort must be very familiar not only with the best in health physics procedures, but also with the details of the cask and contents and the many ways the package can be expected to respond upon being subjected to a variety of conditions. It will

be the responsibility of the shipping agency to provide an escort so qualified.

The air shipment of space reactor auxiliary power systems requires escort but not necessarily escort by a health physicist. This is because radiation, in any appreciable level, will not normally emanate from such packages; a radiation hazard could be present only upon the occurrence of a severe air crash, the kind which personnel aboard the aircraft could hardly survive. The prime functions of such an escort would be to ensure security throughout shipment and to ensure that any recording instruments (which may be recording shock loads, internal pressure, internal temperature) and neutron instrumentation are operating properly. He should periodically check the mechanical integrity of the package, including the containment of inert gas, if such is included in the package, and of any instruments that may be provided to detect the leakage of liquid metal heat transfer fluid from the auxiliary power unit. It will be the responsibility of the escort to ensure that the package is properly handled during loading, off-loading, and tie-down. In the event of any unusual occurrence during flight the escort will advise the aircraft commander. In all probability, this escort will be furnished by the contractor who designed and built the auxiliary power unit; while he need not be a health physicist, it is imperative that he be fully acquainted with the details of the reactor design, the package design, and the response of the reactor to any condition it might encounter during transport. This last requirement will probably make it necessary to appoint a professional man, a scientist or engineer, to escort the package.

In all six categories of shipment considered in this report (irradiated reactor fuel, new reactor fuel, radioactive wastes, contaminated tools and components, space reactor auxiliary power units, and space radioisotope generator units), it is mandatory that the aircrews, and to some extent, the loading and off-loading crews be properly oriented as to the nature of the items they are dealing with. In every case, this responsibility falls upon the agency or organization sponsoring the shipment. While the sponsoring agency may well require the delegation of this task to an industrial concern, the responsibility cannot be delegated. If personnel, and particularly aircraft commanders, are to perform rationally in emergency situations, they must have an understanding of the nature of the cargo which they will handle. Such

preparations as a special short course for these personnel should be considered. It is only upon the assumption that personnel fully familiar with the various packages and their associated hazards will make up the aircrews, that recommendations for the unescorted shipment of new reactor fuel, radioactive wastes, contaminated tools and components, and space radioisotope generator units are made. A point of safety philosophy inferred throughout this report has been that the radioactive material, during shipment, must never leave the control of a responsible authority who understands the nature of the material and that, understanding being a graduated quality, the level of his understanding should be appropriate for the item in question. It has thus been a judgment that a higher level of understanding is required on the part of the custodial authority for irradiated fuel and space nuclear reactor units than for the other types of shipment discussed in this report and the qualifications of the escort have been designated correspondingly.

It is recommended that all personnel involved in the shipment of irradiated reactor fuel, radioisotope generators, and radioactive waste be properly outfitted with film badges and dosimeters when in the near proximity of the radioactive item. Regarding the issue and control of radiation film badges, AFR 161-11, "Film Badge Service," is very specific. The director of medical services at the home base of all the Air Force personnel involved will request the appropriate number of holders and film packets from the USAF Radiological Health Laboratory located at Wright-Patterson AFB, Ohio. The director of base medical services will also be responsible for forwarding the exposed film back to the Radiological Health Laboratory for evaluation. Film badge holders originating from that laboratory will contain two films, one for quarterly and one for monthly evaluation. The Radiological Health Laboratory will be responsible for filling out AF Form 1527, "Dosimeter Film Exposure Listing," and forwarding it to the submitting organizations. The laboratory will also fill out DD Form 1141, "Record of Exposure to Ionizing Radiation," as required by AFR 160-31.

One acquainted with radiation health programs, as practiced among "radiation workers" especially, may object that film badges do not constitute a complete program, and that is right. Frequent, periodic, and

thorough physical examinations are also required. Fortunately, aircrews are subject to such examinations as a matter of course, due simply to the fact that they are on flying status. In the past, radiation workers have been subject to periodic hematological examinations as part of the radiation monitoring program. The National Committee on Radiation Protection no longer recommends these blood counts as a method of monitoring where film badge programs are adequate and where the personnel in question have not been exposed to very high levels of radiation.<sup>18</sup> The periodic examinations given Air Force personnel on flying status by their flight surgeons combined with the film badge programs as specified in AFR 161-11, applied where appropriate, will constitute a completely satisfactory radiation monitoring program for any Air Force personnel involved in the air transport of radioactive materials.

Regarding self-reading dosimeters of the IM-9 (C or D)/PD or IM-135/PD type, these should be furnished by the agency sponsoring the shipment and their use should be thoroughly explained to personnel unfamiliar with this type of sensor. With the shipment of irradiated fuel, the accompanying health physicist should periodically record dosimeter readings as part of his responsibility to control radiation exposure. With other types of shipments, the aircrew should be instructed to periodically check the exposure they have received, themselves, and to record those exposures at least daily.

As the aircrews in question will probably not transport more than one radioactive item in several years, the film badges and dosimeters should be issued to them just prior to the receipt of the package and collected and forwarded to the appropriate agency just after the delivery is made.

With the shipment of irradiated reactor fuel, radioactive waste, and, perhaps, radioisotope generators which are fueled with beta or gamma emitters, it may be desirable to equip personnel handling the package with special film badges in addition to the regular variety which are generally worn on the chest. These special badges would be worn on the hands (either ring badges worn on a finger or a wrist badge, worn much like a wrist watch). The National Committee on Radiation Protection specifies that while an individual radiation worker, in a given quarter year, is allowed no more than a 3-rem whole-body radiation dose, the hands and forearms, head, neck,

feet, and ankles may receive up to a 25-rem dose. The special badges for loading crews, which would measure the dose to the hands and forearms, can also be requisitioned from the USAF Radiological Health Laboratory, through the director of base medical services of the crew members' home base, according to AFR 161-11.

(2) Flight operations

The Military Air Transport Service and the troop carrier organizations of the Tactical Air Command, those Air Force elements which would perform the transport operations discussed in this report, have compiled an exemplary safety record through the years under what have often been extremely adverse conditions. Indeed, it is only because of this record that one can speak realistically of the airlift of nuclear reactor and radioactive materials. As would be expected then, very little change is required in the normal patterns of Air Force flight operations to facilitate the transport of these materials. Only the following are suggested:

(a) Wherever possible, large centers of population should be avoided. It is a known fact that air traffic is more concentrated over such areas and the chances of mid-air collision or other such catastrophes are greater. With the possible spread of radioactive debris, a consequence of a crash, it is particularly undesirable that such a crash occur in a populated area.

(b) All primary and diversionary stopovers and layovers should be made at military air bases. With some operations, security may be a consideration. This has been discussed previously. Obviously, security enforcement is a much easier operation on a military base than at a civilian installation. Also, there is a chance that mishaps may occur with the radioactive package, which, while not catastrophic in nature, require some immediate remedial action. An example of this would be the leakage of some of the coolant from an irradiated fuel element cask. All military air base installations have trained and equipped teams capable of dealing with radioactive contamination (AFR 355-7 levies this requirement upon Air Force installation commanders). Finally, civilian airdromes will, again, most likely be situated very near or in civilian population centers and it is desirable that overflight of such areas be avoided.

(c) Special aircraft-to-tower call-in procedures should be developed, similar to those specified in AFR 55-14 "Precautionary Measures for Aircraft Carrying Hazardous Cargo." These should probably be in code to avoid unduly alarming the local populace and to provide additional security, if such is required. As the transport of such material will, for some time to come, be a rather infrequent operation, the call-in code can be a special one, disseminated on a one-time basis for each shipment by the sponsoring Air Force agency to all possible departure and destination bases. This should be done at the same time that such bases are first made aware of such airlift operations and how the operations may affect the various bases. Sufficient time should be allowed for the different bases to make adequate preparations. If and when the time comes that such shipments are made on a frequent basis, then the writing of an Air Force regulation such as AFR 55-14 would be appropriate.

## 6. PROCEDURES FOR INTERNATIONAL AIRLIFT

As soon as it becomes apparent, in the definition phase of the design of a remote military nuclear power plant system, that the flight of reactor materials and radioactive items over foreign territory is required, the responsible Air Force project officer should seek guidance regarding the complexion of such operations. Such operations may touch upon areas of international sensitivity and it would undoubtedly be wise for the governments of the nations in question to be properly contacted and their concurrence to the planned operations, or the restraints they wish to impose upon them, obtained prior to the issuance of any kind of public pronouncement by the Air Force, the AEC, contractors, etc.

The major clarification required will, of course, concern whether or not such operations can be conducted. Among other things, it must be determined whether it is worth risking the repercussions which might result from a crash in the foreign territory in order to conduct such operations. If such operations are allowed, then lesser areas of required clarification include the designation of civilian air fields where emergency landings can be made, most desirable flight plans, the question of whether and where cargo can be jettisoned in the

event of a mid-air emergency, and the communication channels which should be used in the case of an overdue or crashed aircraft.

AFR 11-5, "Handling Requests for Foreign Military Rights," applies to such operations. Under AFR 11-5, it will be the responsibility of the Air Force project officer for the foreign airlift operations to request diplomatic approval for such operations through the Deputy Director for Policy, Directorate of Plans, Headquarters USAF (AFXPD - PY). Air Force Commands (or any lower echelons thereof) are not permitted to take separate or individual action on such matters with outside agencies such as the Department of Defense or the Department of State. AFR 11-5 specifies the information that must be forwarded to Headquarters USAF. The time at which such application for approval should be made is not specified within this regulation. Presumably, however, such application should be made as soon as the requirement for the foreign operations is identified.

Appendix I

RADIATION PRIMER

The different types of radiation, discussed throughout this report are here defined for the benefit of the reader unacquainted with nuclear physics.

1. Alpha particles which are helium nuclei having two protons and two neutrons each. They may also be referred to as doubly ionized helium atoms as each has the electrostatic charge of two positive electrons. Because of its large mass (4.00278 atomic mass units, amu) relative to other types of radiation, the alpha particle has a lower speed at a specific energy level than other types and is easily absorbed in short distances of air or flesh. (The range of the 4.4- and 4.6-Mev alpha particles given off from uranium-235, in air, runs from 1.15 to 1.2 inches.)

2. Beta particles are nothing more than electrons, one of the basic building blocks of the atom. The charge is that of one electron, though it may be positive or negative in sign. The mass (0.0055 amu) is so small as to be negligible for most considerations. Because of this, the speed for a given energy is considerably higher than that of an alpha particle and its ability to penetrate is greater. (The 0.54-Mev beta particle emitted from  $\text{Sr}^{90}$  has a range in air of approximately 2.2 meters.) It is not as meaningful to speak of the range, through matter, of betas as it is to speak of the range of alpha because alphas, by nature of their relatively large mass, undergo little marked change in direction in their passage through matter while betas are subject to considerable scattering, with frequent changes in direction, as a result of collisions with atomic nuclei and electrons. The mean distance of beta penetration may be misleading in that its path length within the material layer may have been much greater than just the depth of the layer. Figures such as the 2.2 meters in air for 0.54 Mev are acceptable for engineering approximations, however.

3. Bremsstrahlung- When electrons (beta particles) of high speed are slowed down as a result of interaction with matter, continuous X-ray radiation called bremsstrahlung (or sometimes braking or slowing down radiations) are produced. These are electromagnetic radiations which may

be given off in a whole spectrum of energies, up to the maximum energy of the electron. These electromagnetic radiations of short wave length and great penetrating power are usually considered to be emitted in packages of energy called photons, though these photons have no appreciable mass as such. There is no electrostatic charge associated with bremsstrahlung radiation.

4. Gamma rays - In many instances, when a nucleus suffers radioactive decay, the daughter (product) nucleus is not in its lowest energy state or ground state. Within a very short time of its formation the nucleus emits the excess energy in the form of electromagnetic radiation, similar in character to X rays and bremsstrahlung. The wavelengths and energies emitted from a particular nucleus are very well specified at discrete levels by the quantum theory. These electromagnetic radiations are, again, very penetrating, and uncharged. The shielding effectiveness for gamma increases with increases in the atomic number of the absorber material.

5. Neutrons - The neutron is another basic building block of the atom or more properly, the nucleus. It has a large mass (1.00897 amu) and no charge. The fission process is the most famous source of neutrons although there are some short-lived radioisotopes that emit neutrons by spontaneous fission and neutrons may be emitted by the interaction of alpha particles with boron, lithium, or beryllium, or by the interaction of moderately energetic gamma rays with deuterium and beryllium. Neutrons interact with matter by absorption into another nucleus or by scattering rather than by ionization as do charged particles. The shielding effectiveness decreases with increases in the atomic number of the material interacting with the neutrons as the lighter atoms "drain off" more of the neutron's kinetic energy.

Appendix II

RADIATION PROTECTION STANDARDS

1. The purpose of this appendix is to present the definitions of the various units and types of radiation, and the philosophy of radiation protection and radiation protection guidance which pertains to air transport of radioactive material. Much of this appendix is taken from an excellent discussion of the subject contained in Ref. 21.
2. The basic radiation protection guidance follows the recommendations of the Federal Radiation Council.<sup>22</sup> The Radiation Protection Guides ("defined as the radiation dose that should not be exceeded without careful consideration of the reasons for doing so") are taken directly from Ref. 22.

The adoption of the Radiation Protection Guidance for Federal Agencies has effected a change in terminology for defining and describing maximum permissible dose or exposure (MPD or MPE) as stated by the National and International Committees on Radiation Protection (NCRP & ICRP).<sup>23, 24, 25</sup> This report will use the terminology recommended by the Federal Radiation Council. The term "Radiation Protection Guide" replaces "maximum permissible dose"; "Radioactivity Concentration Guide," replaces the "maximum permissible concentration "

3. \* Units of radiation dose and contamination measurement.

3.1 Dose units. The units of radiation dose are based on how the physical measurement was performed and on observed or postulated biological effects. The more frequently used dose units are the roentgen, the rad, and the rem.

3.1.1 Roentgen (r). The roentgen is the unit of exposure dose of gamma (or X) radiation for energies up to 3 million electron volts (Mev). One r is an exposure dose of gamma (or X) radiation such that the associated corpuscular emission per 0.001293 gram of air produces ions carrying 1 electrostatic

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\*This part of the discussion is abstracted from Ref. 21.

Unit (esu) quantity of electricity of either sign. At standard temperature and pressure, 0.001293 gram of air occupies 1 cc. Restated, the r is a unit of exposure dose for gamma and X radiation only (below 3 Mev) and expresses the ionization in air that is equivalent to the liberation of 1 esu of charge per cc of air under standard conditions. Likewise, 1 r is equivalent to an energy absorption of 87 ergs per gram of air, which is, in turn, equivalent to an energy absorption of 93 ergs per gram of mammalian tissue.

3.1.2 Rad. The rad is the unit of absorbed dose. It is defined as the absorption of 100 ergs of radiant energy per gram of material (tissue, etc.) at the point of interest. The rad applies to any ionizing radiation and to any absorbing medium.

3.1.3 Rem. The rem (rad-equivalent-man) is the dose of radiation that produces the same biological effect, in the particular circumstances, that would be produced by 1 rad of X radiation (generally at 250 kev). The rem applies to all types of ionizing radiation. The dose in rems is equal to the dose in rads multiplied by the RBE (relative biological effectiveness) for the corresponding biological effect. The RBE is defined as the ratio between the gamma or X-radiation dose and the dose of the radiation in question that is required to produce the same biological effect. Different types of radiation absorbed in a specific organ and delivering equal amounts of energy (ergs/gm) can result in different biological effects on that organ. Although it has been observed that the different types of ionizing radiations produce qualitative effects that are indistinguishable from each other, they do not necessarily produce quantitative effects that are equivalent. That is, the biological effects from different radiations appear to be the same, but the magnitudes of these effects may vary with the type of radiation, even though the energy delivered to the tissue in question is the same. The concept of the RBE quantitatively compares the effects of the various ionizing radiations.

The r, rad, and rem units are all currently used. The r is used to signify gamma- and X-radiation exposure dose; the rad, gamma-, X-, beta-, and neutron-radiation absorbed dose; and the rem, the RBE dose for any type of radiation. For practical purposes, the r (equivalent absorption of 93 ergs/gm in tissue) and the rad (absorption of 100 ergs/gm in tissue) are considered equivalent for measuring gamma- and X-radiation dose. However, strict use of the rad requires definition of the type of radiation and the material in which it was measured. The rem unit is used to signify the radiobiological effects

on man, that is, the product of the dose in rads and an agreed conventional RBE value with respect to a particular form of radiation effect.

3.2 Contamination units. The units for measuring radioactive contamination are based on the physical properties of the radioactive material and the contaminated surface and on the method of measurement. Gamma-emitting contaminants are measured by their exposure dose rate (r/hr or mr/hr) at some specified distance from the source.

Beta-emitting contaminants are usually measured near contact. Since measurements are usually measured with gamma-calibrated instruments, the type of instrument and the geometry of the measurement should be specified. Beta measurements are expressed in rad/hr or mrad/hr units, and should be interpreted to indicate only the approximate beta dose rate, since no common beta reference standard has yet been established.

Alpha-emitting contaminants are measured by the surface activity of the contaminated object in units of counts per minute (cpm), or disintegrations per minute (dpm), per probe area of the measuring instrument. Again, the type of instrument and the geometry of the alpha particles measured by the detecting and counting system of the instrument, uncorrected for counting efficiency need be specified in any such measurement. The dpm unit corrects for the counting efficiency of the instrument, assuming that all the alpha contamination is on the surface. However, it should be pointed out that contamination is generally absorbed into surfaces, so that the type of surface must be considered in estimating the absolute alpha contamination. Equal contamination on a smooth surface and a porous surface will produce different measurements, the smooth surface having the higher reading. Alpha contamination measurements, at best, are only qualitative.

A comprehensive discussion of monitoring instruments and procedures may be found in Ref. 26.

#### 4. Basic radiation protection guidance.

Exposure to ionizing radiation should always be kept to a minimum, since, strictly speaking, there is no such thing as a tolerance or permissible dose when all the possible effects of radiation on the individual and on future generations are included. However, it is often impractical if not impossible, to

eliminate exposure completely. Therefore, the problem is, in practice, to limit the exposure to that which is not an unacceptable risk to the individual or to the population. As stated in Ref. 21, "There should not be any man-made radiation exposure without the expectation of benefit resulting from such exposure . . . There can be no single permissible or acceptable level of exposure without regard to the reason for permitting the exposure. It should be general practice to reduce exposure to radiation, and positive effort should be carried out to fulfill the sense of these recommendations. It is basic that exposure to radiation should result from a real determination of its necessity."

4.1 Table 3 presents the Radiation Protection Guides for normal peacetime operations.<sup>22</sup> Under "Type of exposure," the radiation worker is one whose occupation entails exposure to ionizing radiation. The population refers to all others.

Table 3  
RADIATION PROTECTION GUIDES<sup>22</sup>

Type of exposure	Condition	Dose (rem)
<b>Radiation worker:</b>		
(a) Whole body, head and trunk, active blood-forming organs, gonads, or lens of eye.	accumulated dose	5 times the number of years beyond age 18
(b) Skin of whole body and thyroid	13 weeks year	3.
(c) Hands and forearms, feet and ankles	13 weeks year	30. 10. 75.
(d) Bone	13 weeks body burden	25. 0.1 microgram of radium-226 or its biological equivalent
(e) Other organs	year 13 weeks	15. 5.
<b>Population:</b>		
(a) Individual	year	0.5 (whole body)
(b) Average	30 year	5 (gonads)

4.2 Under "Condition," the accumulated dose specifies the accumulated (maximum lifetime) guidance dose for radiation workers, equal to  $(N-18) \times 5$  rems where  $N$  is the individual's age. The quarterly (13-week) guidance dose is 3 rems. This quarterly limit permits radiation workers to accumulate dosage at the rate of 3 rems/quarter or 12 rems/year if the accumulated dose is not exceeded. The term "body burden" listed under "Condition," signifies that amount of radioactive material in the body such that the resultant dose will not exceed the guidance dose. For the bone as the critical organ, the guidance dose is that dose produced by 0.1 microgram of radium-226 or its biological equivalent. The critical organ is that organ of the body in which the radioactive material first produces the guidance dose.

4.3 For the individual in the population, the basic guide for the 1-year whole-body dose is 0.5 rem. This guide applies when the individual whole-body doses are known. As an operational technique, when the individual whole-body doses are not known, a suitable sample of the exposed population should be developed whose protection guide for yearly whole-body dose will be 0.17 rem per capita per year. It is emphasized that this is an operational technique that should be modified to meet special situations.<sup>22</sup>

4.4 Dosage is controlled by limiting (1) the external body exposure to radioactive materials or radiation-producing equipment and (2) the internal body exposure to radioactive materials taken into the body by inhalation ingestion, and absorption. The Radiation Protection Guides of table 3 establish the limiting external and internal doses for normal operations.

4.5 The external exposure is conveniently controlled by limiting dose rate and/or stay-time (time the radiation workers spend in a radiation field). The control of internal exposure (that is, exposure of the active blood-forming organs, glands, bone, and other organs of the body due to the inhalation, ingestion, or absorption of radioactive materials into the body) is controlled by limiting the stay-time and the amount of radioactive contamination in air and water, and on surfaces of objects. The contamination levels that will not produce a dose greater than those specified in table 3 are defined as the Radioactivity Concentration Guides. The Radioactivity Concentration Guides are based on such levels of contamination and conditions of exposure that the

Radiation Protection Guides will not be exceeded. For example, the Radioactivity Concentration Guide for air contamination is based on that concentration of radioactive aerosol, normally specified in units of microcuries per cubic centimeter ( $\mu\text{c}/\text{cc}$ ), for the conditions of 40 hrs/wk occupational exposure, such that the Radiation Protection Guides in table 3 are not exceeded.

4.6 If a radiation worker is subjected to both external and internal exposure, as for example with a person working in a contaminated area, then the radiation guidance for external exposure and the concentration guides for internal exposure must be adjusted so that the basic guides in table 2 are not exceeded.

#### 5. Normal and special radiological operations

Those radiological operations that can be performed without exceeding the Radiation Protection Guides for peacetime operations may be classified as normal operations. However, there are some operations that cannot be conducted expeditiously within the quarterly guidance dose of 3.0 rems.

5.1 The alternatives to exceeding the quarterly guidance dose are to delay operations or to rotate personnel so as to conserve individual dosage. However, neither alternative may be effective because of the urgency of the program (time and scheduling requirements) or the lack of sufficient personnel for effective rotation. Also, the monetary cost may be excessive. Therefore, the Federal Radiation Council recommends establishing special operations that allow personnel to receive 12 rems/year without limitation on the time period in which this dose is received provided the accumulated dose,  $(N-18) \times 5$  rems, is not exceeded. It is believed that acceptance of this guidance for special operations will not appreciably increase the risk over that of the basic guidance (table 2). However, in keeping with the principle of minimizing dose whenever possible, it is prudent to establish special operations only when they are operationally warranted. A special operation is not a license for relaxed rad-safe procedures, but rather it is a statement of a critical operational demand requiring detailed planning and strict rad-safe controls.

#### 6. Internal radiation hazards

Table 3 presents the Radiation Protection Guides for all conditions of exposure. To assist in the control of radiation received by personnel, Radioactivity Concentration Guides are recommended for sources of potential internal

body exposure. Internal body exposure results from radioactive material being inhaled, ingested, or absorbed into the body. Once within the body, they emit radiation continuously until eliminated or decayed. Different elements accumulate preferentially in different organs. The organ in which a given radioisotope alone first produces the guidance dose is called the critical organ for that isotope. The body burden is the amount of radioactive material in the body. The guidance body burden for a specific isotope is that amount of the isotope that will produce an exposure equal to the guidance dose specified in table 3 with a given exposure rate (usually 40 to 168 hours/week). For a discussion of the hazards involved in the air transport of nuclear materials, the Radioactivity Concentration Guides are not applicable. This is because these specifications are evaluated for long exposure times to nuclear plant effluents or radioactive wastes discharged to the atmosphere or water supply of inhabited areas. While similar biological uptake mechanisms exist for loading or air crews via the "hand to mouth route" for liquids and/or the inhalation of steam or coolant vapor puffs (of short stay times) following the spillage of liquid radioactive waste or the loss of contaminated coolant from a fuel element cask, the exposure times of these personnel would be much smaller than those for which the Radioactivity Concentration Guides are calculated. Such guides for each given situation could, however, be calculated for the air transport of radioactive materials provided the following are specified:

- 6.1 Method of uptake
- 6.2 Relative concentrations of the different radioisotopes
- 6.3 Exposure time

As the above-mentioned items vary so widely with different hypothetical accidents, concentration guides cannot be used for the planning of either individual air shipments or container designs. Hence, those concentrations compiled in Ref. 24 will be disregarded and the calculation of other concentration guides will not be considered.

## Appendix III

PROPOSED CRITERIA FOR IRRADIATED FUEL ELEMENT  
CONTAINERS INTENDED FOR AIR SHIPMENT1. Introduction

This proposed specification sets forth packaging design criteria and standards for the transport of irradiated nuclear reactor fuel elements on USAF aircraft. This specification applies to both new and used containers. Any deterioration in the properties here listed as a result of usage which cause the container to fall short of any of these criteria renders the container unacceptable for further usage.

2. Nucleonics

2.1. The transportation of irradiated fuel elements will be permitted only if either:

2.1.1. The number of fuel elements in a single cask does not exceed 75 percent of the number required to achieve criticality under the conditions in 2.2 of this section, or

2.1.2. The effective neutron multiplication constant  $k_{eff}$  does not exceed 0.9 under the same conditions. (A self-sustaining chain nuclear reaction or criticality is taken to occur when  $k_{eff}$  equals unity.)

2.2. In determining whether either of the conditions specified in paragraph 2.1 exists, the following assumptions shall be made.

2.2.1. Water is in and around the cask in such quantities and so distributed as to cause maximum reactivity. If more than trace quantities of beryllium, graphite or heavy water are present, then further evaluation is required.

2.2.2. If reactivity decreases with irradiation, the fuel elements are unirradiated. If reactivity increases with irradiation, the fuel elements are irradiated to the condition of maximum reactivity.

2.2.3. Fuel elements are in the most reactive array, unless the proposed

spacing will assure less than maximum reactivity and the fuel elements cannot be rearranged into a more reactive array.

2.2.4 Structural materials, including spacers and neutron poisons intentionally built into the cask components or fuel elements may be considered if their effectiveness as neutron poisons cannot be reduced by application to the cask of the forces described in section 9., by melting of the fuel or neutron poison, or by any other cause under normal conditions of transport or in the event of an accident.

### 3. Radiation shielding

3.1 The external radiation level shall not exceed 200 milliroentgens per hour at the accessible surface of the cask or of the external structure, if used, or 10 milliroentgens per hour at a distance of 1 meter from the accessible surface of the cask or the external structure, except that when transport of a single cask has the exclusive use of an aircraft or other vehicle the radiation level shall not exceed 200 milliroentgens per hour at the accessible surface of the cask or 10 milliroentgens per hour at a distance of 3 meters from such surface.

3.2 The shield shall be so constructed that in the event of the escape of all substances which are liquid at ordinary temperatures, and in the event of loss of all external shielding which is not an integral part of the cask, radiation levels will not exceed 1 roentgen per hour at a distance of 1 meter from the accessible surface of the cask. Shielding provided by any solid coolant may be taken into account in determining compliance with this paragraph only if that coolant will remain in the cask in the event of any accident.

3.3 Shielding shall prevent beaming of radiation to the exterior of the cask, and shall be free of voids other than controlled voids designed to contain shielding in the event of melting.

3.4 Shielding shall be supported in the cask so that it cannot change position or configuration under normal conditions of transport. The inner shell of the cask shall be supported so that it will not be displaced if the shielding should melt.

3.5. Any pipes or other attachments which might contain radioactivity during shipment shall be shielded in accordance with paragraph 3.2 of this section, taking into account the possibility of the flow of liquid primary coolant as a result of thermal expansion or the release of radioactive gas from fuel elements.

3.6. Prior to the first use of any cask, the responsible shipping authority shall determine the effectiveness of the cask shielding and shall establish the absence of cracks, pinholes, uncontrolled voids or other defects. Prior to each shipment of any cask the responsible authority shall determine that the external radiation levels of the loaded cask comply with the provisions of paragraph 3.1.

4. Heat dissipation

4.1. The cask shall be so constructed and loaded that under normal conditions of transport:

4.1.1. The temperature of any easily accessible surface of the cask or of any external structure will not, at any time, exceed 180°F.

4.1.2. Any coolant or cooling system meets the following conditions:

4.1.2.1. Primary gaseous or liquid coolant is not circulated outside the shielding of the cask.

4.1.2.2. Provision is made to prevent freezing of any liquid coolant under the most adverse weather conditions to be anticipated with any proposed fuel loading. The most adverse weather conditions for the different regions of the earth are to be taken as those given in Mil Std 210. Any antifreeze is to be of a type which will not, under such circumstances, undergo chemical change which might impair the efficiency of the cooling system.

4.1.2.3. The temperature of any liquid primary coolant will remain at all times at least 20°F below its boiling point at the anticipated operating pressure within the cask, under the conditions described in paragraph 4.2.

4.1.2.4. Any primary coolant will not cause significant corrosion of the fuel element, fuel element cladding or any interior surface of the cask, or react with any components of fuel elements or cask with which it might come in contact.

- 4.1.2.5. The gage pressure of the primary coolant will not exceed 50 pounds per square inch or 50 percent of the design pressure, whichever is lower.
- 4.1.3. The maximum surface temperature of any fuel element will be no higher than the highest of the following:
- 4.1.3.1. 300 degrees F;
- 4.1.3.2. The maximum temperature which the type of fuel element has maintained during at least 30 days of irradiation in an operating reactor, without failure of any portion of the fuel element, as measured directly or calculated from experimental data; or, if the type of fuel element has not been irradiated for at least 30 days, then the average temperature which the type of fuel element has maintained during the maximum period of irradiation and not less than two days;
- 4.1.3.3. 300°F below the failure temperature of the type of fuel element, with due consideration for the irradiation and decay history of the fuel elements to be shipped in the cask.
- 4.1.3.4. For the purposes of this paragraph, failure temperature shall be considered to be the minimum temperature at which initially sound fuel elements of the character and amount being considered as the cask load will, within 48 hours, release to the primary coolant 100 curies of beta-gamma radioactivity or one curie of alpha radioactivity. In no case may failure temperature be taken as higher than the melting point of the fuel or cladding, whichever is lower.
- 4.2 The cask shall be so constructed and loaded that, in the event all liquid or gaseous coolant should be lost but solid coolants including granular solids remain in the cask, the maximum surface temperature of any fuel element will not exceed a temperature of 100°F above the temperature specified in subdivision 4.1.3. of this section. Fuel element surface temperatures may exceed the melting point of the cask shielding material if melting of the shielding material will not occur.
- 4.3. Computation of the temperature within the cask shall in every case assume ambient air at 100°F without wind, with maximum solar heat load anticipated for the proposed route (as given in Mil Std 210) and conditions of

shipments and, in the circumstances described in paragraph 4.2. of this section, loss of any sun shade or enclosure which would interrupt solar radiation.

4.4 Prior to the first use of any cask, the licensee shall experimentally verify the calculated heat transfer characteristics of the cask and any mechanical cooling device under normal conditions of transport.

4.5. Means shall be provided for measurement, either directly or indirectly, of the internal cask wall temperature at any time.

5. Cask pressurization and leakage

5.1. The cask shall be capable of withstanding a design pressure equal to an internal gage pressure of not less than 30 pounds per square inch or twice the operating pressure, whichever is greater, with stresses which do not exceed the yield strength of the material of which the cask is composed.

5.2. Means shall be provided for applying a seal so that the lid cannot be opened without destroying the seal.

5.3. Valves, piping, expansion tanks and other external functional parts of the cask shall be protected from mechanical damage to be anticipated during normal handling and transport. Any such part projecting beyond the contour of the body of the cask or the lid shall be so constructed or protected that mechanical damage will not cause loss of shielding which would permit the level of radiation to exceed 1 roentgen per hour at any point one meter from the accessible surface of the cask.

5.4. Any valve, other than pressure relief devices, through which primary coolant could leak during transport to such an extent that the level of radiation could exceed 1 roentgen per hour at a distance of one meter shall be protected by a sealed, gasketed or welded closure adequate to retain leakage and shielding sufficient to reduce radiation to that level. A means shall be provided for detecting and safely removing coolant which may leak through any such valve.

5.5. Any valve through which primary coolant can flow shall be provided with a lock, which shall be locked during transport.

5.6. Any cask in which the operating pressure exceeds atmospheric pressure during transport shall be equipped with a pressure relief device which will

prevent exceeding 75 percent of the design pressure prescribed by paragraph 5.1.

- 5.7. Each cask vent or pressure relief device shall be equipped with a filter capable of removing at least 99.9 percent of particles greater than 0.3 micron in size, and of sufficient capacity for the maximum rate of discharge of the vent or device. The filter shall be protected against impairment of efficiency by mechanical shock or absorption of moisture.
- 5.8. When the total amount of iodine 131 which will be released from the fuel element under the conditions specified in paragraph 4.2. exceeds 10 curies or the amount of iodine 129 which will be released under those conditions exceeds 1 curie, the pressure relief system shall be equipped with an iodine gas removal device having a removal efficiency and retention capacity in the anticipated temperature range adequate to reduce the total iodine which may be released from the cask to those quantities.
- 5.9. In any case in which an explosive mixture of gases or of gas and vapor may accumulate within the cask, provision shall be made to prevent explosion by equipping the cask with a flash arrester, prepurging void spaces with inert gas, adding an appropriate catalytic re-combiner, or assuring that the maximum temperature of the fuel will remain under all circumstances, including loss of all liquid or gaseous coolant and with all mechanical cooling devices being inoperative, at least 200°F below the ignition temperature of the explosive mixture.
- 5.10. Means shall be provided, either by a sampling port or pipe connection or otherwise, for obtaining samples of gas or liquid coolant in the cask while the lid is in place and the cask is in the vehicle or vessel.
- 5.11. Means shall be provided for safely equalizing the internal pressure of the cask with the pressure of the atmosphere.
- 5.12. The pressure relief system shall have sufficient capacity to avoid a pressure surge exceeding the design pressure of the cask in the event of steam generation resulting from the introduction of water after loss of gas or liquid coolant.

5.13. Pipe connections shall be provided capable of removing substantially all liquid from the interior of the cask while the lid is in place.

5.14. Activity of coolant. If all or any part of the primary coolant is liquid or gas, the responsible shipping agency shall take a representative sample of the coolant prior to each shipment. The sample shall not be taken until at least 4 hours after the fuel elements and the primary coolant have been placed in the cask. The responsible shipping agency shall measure the activity of the sample and the following limits of activity shall not be exceeded:

Liquid coolant:

$10^{-5}$  curie of beta or gamma activity per milliliter.

$10^{-7}$  curie of alpha activity per milliliter.

Gas coolant:

$10^{-7}$  curie of beta or gamma activity per milliliter.

$10^{-10}$  curie of alpha activity per milliliter.

5.15. Prior to shipment, the licensee shall determine that the internal pressure of the cask will not exceed 40 pounds per square inch gage or 50 percent of the design pressure, whichever is less, under normal conditions of transport.

5.16. Pressure Test. Prior to each shipment, the licensee shall test the loaded cask with primary coolant in place for leaktightness using an internal pressure at least 50 percent higher than the maximum anticipated internal gage pressure, and in any event, not less than 15 pounds per square inch.

## 6. Temperature

6.1. The casks shall be capable of withstanding exposure to the following low temperatures, under the conditions specified, for a period of 24 hours, without loss of shielding or cooling efficiency.

6.1.1. General world-wide use: Paragraph 2.2.1. of Mil Std 210 "Climatic Extremes for Military Equipment," will apply.

6.1.2. Arctic winter use: Paragraph 2.2.1. of Mil Std 210 will apply.

6.1.3. Moist tropics: No specification is made (paragraph 6.1.1. applies).

6.1.4. Dry desert: No specification is made (paragraph 6.1.1. applies).

6.2. The casks shall be capable of withstanding exposure to the following high temperatures, under the conditions specified, for a period of 24 hours, without loss of shielding or cooling efficiency:

6.2.1. General world-wide use: Paragraph 2.1.1. of Mil Std 210 will apply.

6.2.2. Arctic winter: No specification is made (paragraph 6.2.1. applies).

6.2.3. Moist tropics: Paragraph 2.1.3. of Mil Std 210 will apply.

6.2.4. Dry desert: Paragraph 2.1.1. of Mil Std 210 will apply.

6.3. An application for waiver from any of these temperature specifications may be made by the sponsoring agency if it can be proved, conclusively, that the cask will never be subject to such temperature extremes in any future use.

## 7. Humidity

7.1. The moisture contained in any atmosphere the cask may encounter, for a period of 24 hours, shall in no way impair the shielding or cooling efficiency. These environments, for the different conditions specified, are:

7.1.1. General world-wide use: Paragraph 2.3.2. of Mil Std 210 shall apply as regards high humidity extremes while paragraph 2.4.1. shall apply as regards low humidity extremes.

7.1.2. Arctic winter: Paragraph 2.3.3. of Mil Std 210 shall apply as regards high humidity extremes while paragraph 2.4.2 shall apply as regards low humidity extremes.

7.1.3. Moist tropics: Paragraph 2.3.2. of Mil Std 210 shall apply as regards high humidity. There is no specification made for low humidity.

7.1.4. Dry desert: Paragraph 2.4.6. of Mil Std 210 shall apply as regards high humidity while paragraph 2.4.4. shall apply as regards low humidity.

## 8. Blowing sand and dust

Blowing sand and dust conditions, as specified in Mil Std 210 shall not

penetrate to the inside of the container or in any way impair the shielding or cooling efficiency of the cask. References specifying the blowing sand and dust conditions are:

8.1. Blowing sand: Paragraph 2.6.2.4. of Mil Std 210

8.2. Blowing dust: Paragraph 2.8.3.1. of Mil Std 210

9. Structural integrity

9.1. The cask, regarded as a simple beam supported at its ends along the major axis, shall be capable of withstanding a static load, normal to the major axis, uniformly distributed along the major axis, and equal to 10 times the weight of the cask when fully loaded without exceeding the ultimate strength of the cask, considered as a whole.

9.2. The cask, either alone or in combination with any shock absorbing structure securely fastened to it, shall be capable of withstanding an impact force in a direction normal to any side, including the top or bottom, caused by a free fall of the loaded cask through a distance of 15 feet upon an unyielding horizontal flat surface, without either:

9.2.1. Exceeding the ultimate strength of any structural portion of the cask, or

9.2.2. Deforming the cask to an extent which would permit the escape of fuel elements or portions of them or permit the level of external radiation to exceed 1 roentgen per hour at any point one meter from any accessible surface of the cask.

A force equal to 60 times the weight of the loaded cask and lasting not less than 16 milliseconds may be deemed equal to the impact force described in this paragraph.

9.3. The lid and the lid closing mechanism, including bolts, clamps and other positive fastening devices, shall be capable of withstanding a force in any direction of at least 60 times the weight of the lid and the contents of the cask and, if the lid projects above the body of the cask, at least 15 times the weight of the loaded cask, without stress at any point exceeding the ultimate strength of the material. The duration of the applied force shall be assumed to be not less than 16 milliseconds.

- 9.4. Fuel element holders shall be adequate to protect fuel elements from mechanical damage under normal conditions of transport, and to avoid criticality when the cask is subjected to the forces described in 9.1., 9.2. and 9.7. if preservation of the geometry of the fuel elements is necessary for that purpose.
- 9.5. Neutron poisons shall be so constructed and installed that application to the cask of the forces described in 9.1., 9.2. and 9.7. will not result in loss of efficiency and so that built-in neutron poisons will remain present and effective at all times.
- 9.6. Any internal container for one or more fuel elements shall be leaktight and shall be so constructed that the maximum stress in the material of the container will not exceed the yield strength under normal conditions of transport.
- 9.7. Exterior and attachments. Every exterior surface of the cask shall be capable of withstanding a force equal to 30 times the weight of the loaded cask, applied normal to that surface and over any circular area 6 inches in diameter, without exceeding the ultimate strength of the material of which the exterior surface is constructed. The duration of the applied force shall be assumed to be not less than 16 milliseconds. An exterior surface of steel with a total thickness equal to or greater than that indicated below satisfies the requirements of this paragraph.

Loaded cask weight (in pounds)	Thickness of steel (in inches)
5,000 to 20,000	3/8
20,000 to 30,000	1/2
30,000 to 40,000	5/8
40,000 to 55,000	3/4
55,000 to 70,000	7/8
70,000 to 90,000	1

10. Vibration

The cask shall be capable of withstanding vibration incident to shipment without impairing the integrity of the closure or of the cask itself.

The following frequencies will be regarded as representative of those to be encountered in military aircraft:

Frequencies (c/s)	Half amplitude in inches		
	Central region	Power unit region	Extremities
3	0.010		0.033
15	0.009	0.015	0.016
30	0.008	0.014	0.013
50	0.006	0.012	0.009
100	0.004	0.005	0.005
150	0.003	0.004	0.003
400	0.001	0.001	0.001
500	0.001	0.001	

The cask and its ancillary equipment (if any) shall be able to endure these vibrations at each frequency for a period of 3 hours.

11. Weight, size, and floor pressure in aircraft

11.1. The allowable cask weights for military air transport shall be computed individually (from the -1 technical order) for the mission and particular aircraft in question.

11.2. The allowable pallet floor loadings will be taken as given in the -9 technical order for the particular aircraft in question.

11.3. The allowable, overall dimensions of the package (to include cask, pallet, crash frame, and other attached items) are to be taken as given in the appropriate -9 technical order or U. S. Air Force Specification Bulletin 518 for the particular aircraft in question.

11.4. If at all possible, the cask pallet should be designed to be compatible with the Air Force's 463L, Materials Handling Support System.

12. Pick-up points and tie-down fittings

12.1. The design of every cask whose destination, when loaded with irradiated fuel elements, is the Idaho Chemical Processing Plant (ICPP) must be in compliance with the "General Cask Acceptance Criteria" (Subappendix 1) and the "Special Cask Design Requirements at the I. C. P. P." (Subappendix 2) as issued by that facility. The design of every cask whose destination, when loaded with irradiated fuel elements, is the Savannah River Plant, must be in compliance with the "Cask Acceptance Criteria, Receiving Basin for Off-Site Fuels, Savannah River Plant" as issued by the USAEC, Savannah River Operations Office (see Subappendix 3). The general acceptance criteria require that the cask must be approved by the Bureau of Explosives (of the Association of American Railroads) for the shipment of the specific material involved and that this approval must be evidenced by a Bureau of Explosives approval number inscribed on the container and by a copy of the request for approval along with the approval of the Bureau of Explosives made available to the AEC office administering the receiving site.

12.2. The cask shall be provided with adequate hooks, handles, trunnions, skids, base plate, or other devices which will permit adequate tie-down and support during transport and facilitate normal handling.

12.3. Any device which is attached to the cask and which is designed or could be employed to tie the cask down during transport shall be sufficient to withstand a static force having a vertical component of 2 times the weight of the loaded cask (up) and 4.5 times the weight of the loaded cask (down) and a horizontal component of 10 times the weight of the loaded cask without exceeding the yield strength of the materials in the device.

12.4. Any device which is attached to the cask and which is designed to lift the cask shall be capable of lifting 6 times the weight of the loaded cask without exceeding the yield strength of the materials in the device.

12.5. Any device which is attached to the cask and which is designed to lift the lid shall be capable of lifting 6 times the combined weights of the lid and contents of the cask without exceeding the yield strength of the materials in

the device. If the device is attached to the lid during transport, it shall be securely covered and marked unless it complies with paragraph 12.4 of this section.

12.6. Any package (cask and pallet) which is to be capable of being jettisoned from an aircraft having a sufficiently grave in-flight emergency must meet the general design requirements for parachute equipment as given in the -9 technical order of the aircraft in question.

### 13. Materials

13.1. The cask shall be so constructed that decay heat will not, under normal conditions, significantly impair its effectiveness as a shield or container either through melting of the shielding or cracking of the cask, cause any internal fuel container to melt, or alter the form or nature of the fuel.

13.2. Materials of which the cask and any components or internal structures are constructed shall be such that there is no significant chemical, galvanic or other reaction between them or with fuel elements. Military Standard MS 33586, "Metals, Definition of Dissimilar," will apply. Metals classified as dissimilar will not be brought into intimate contact with one another, unless it can be proved that galvanic interaction will not occur.

13.3. All welding and brazing of the cask shall be performed in a workman-like manner, free of significant defects, and shall provide a mechanical joint efficiency of not less than 85 percent. The melting point of any brazing material shall not be lower than 1000 degrees F.

13.4. Uranium or any other substance having a melting point lower than 1000°F used as shielding shall be completely encased in welded mild steel or other material having a melting point higher than 1000°F, having all joints welded and having a minimum wall thickness of 1/8 inch for not more than 6 inches of shielding thickness. If shielding material has a melting point lower than 1000°F, a provision shall be made for assuring, by deformation of the container walls or controlled voids in the shell or similar means, that the welded shell will not rupture if the cask is exposed to a standard one-hour fire as defined in paragraph 14 to this specification. The use of fusible plugs or discs or other types of vents in order to avoid rupture of the welded shell is

prohibited if such use could result in loss of shielding to such an extent that the level of radiation could exceed 1 roentgen per hour at a distance of 1 meter from the accessible surface of the cask.

13.5. Any hole drilled in the body of the cask and extending into low melting point shielding material shall terminate within a boss pad welded to the shell of the cask body through which the hole penetrates, unless loss of shielding material through the hole cannot occur.

13.6. Any piping passing through lead shielding shall be so installed that damage will not result from settling or deformation of the lead during handling and transport.

13.7. Neutron poisons. The licensee shall perform periodic tests to establish that any built-in neutron poisons are present and effective in accordance with the approved cask design.

13.8. All inner cask surfaces which are likely to be contacted by the coolant will be of stainless steel or other material capable of being easily decontaminated. All external surfaces must be accessible for decontamination.

14. Survivability in fire

14.1 The cask and shield shall be adequate to prevent reduction of effectiveness of shielding which would permit radiation levels in excess of the limits prescribed by paragraph 3.2. or loss of radioactive materials, as a result of the action of the standard one-hour fire, water, and the application to the cask of the forces described in paragraph 9.; corrosion and pressure; contamination of the surfaces of the cask and shield; and explosive or other effects of the gases which may be generated by radiolytic, chemical or other processes.

14.2. The "standard one-hour fire" mentioned in this part assumes exposure for one hour to a fire in which the following temperatures are reached at various times after the beginning of the fire:

- 1000 degrees F after 5 minutes;
- 1300 degrees F after 10 minutes;
- 1550 degrees F after 30 minutes;
- 1700 degrees F after 1 hour.

NOTE: The standard fire is described in specifications of the National Fire Protection Association (NFPA, No. 251) and the American Society for Testing Materials (ASTM, Design E 119-50). Details of methods for testing by means of the standard fire may be found in the cited references.

15. Ruptured fuel elements

15.1. Prior to the transport of any fuel element having any break or defect in its cladding, the shipping agency shall completely enclose the fuel element in an internal container, unless the fuel element can be carried in the cask without significant reaction or contamination of the primary coolant in excess of one-tenth of the permissible limits prescribed in paragraph 5.14.

15.2. Prior to each shipment of any cask the shipping agency shall survey representative parts of the surface of the loaded cask for external contamination by wiping an area of approximately 100 square centimeters with clean absorbent paper, applying moderate finger pressure, and measuring contamination on the dry paper through standard counting techniques for beta-gamma and alpha activity. Surface contamination so measured shall exceed neither 4,000 disintegrations per minute per 100 square centimeters of beta-gamma activity nor 500 disintegrations per minute per 100 square centimeters of alpha activity.

16. Marking

16.1. Irradiated fuel element casks should be clearly marked, as follows:

16.1.1. "Do Not Remain in or Near this Package Unnecessarily."

16.1.2. "Notify shipper or (name and address of emergency coordination center) immediately, in the event of any irregularity."

16.1.3. "(name of plant) REACTOR IRRADIATED FUEL ELEMENTS."

16.1.4. "Avoid Contact with Leaking Contact."

16.1.5. "When this container is devoid of radioactive material, this sign must be removed."

The sign should be so attached as to remain in place and legible during and after having been ejected from an aircraft in distress and having fallen to earth beneath a deployed parachute.

16.2. If, during any portion of the shipment, routine civilian transport channels are to be utilized and the cask is not to be under qualified military escort, irradiated fuel element casks are to be marked in compliance with the appropriate provisions of AFM 71-4, "Packaging and Handling of Dangerous Materials for Transportation by Military Aircraft," in addition to those specified in section 16.1. of these criteria. In particular, when the unescorted cask is loaded with irradiated fuel element material, AF Form 1609 shall be properly filled out and attached to the cask. When the cask is empty, whether escorted or unescorted, in transit or in storage, AF Form 1595 should be firmly attached and displayed.

Appendix III

Subappendix 1

GENERAL CASK ACCEPTANCE CRITERIA  
(Applicable at all sites for routine handling)

- A. Shipments will be accepted from rail or motor carriers. Under certain conditions water shipments can be accepted at all but the Idaho site.
- B. To insure compatibility with existing handling facilities, it is necessary that six complete sets of design drawings of the cask and transfer bucket and method of attachment to the shipping vehicle proposed for use in shipment of fuel elements be transmitted to the AEC office administering the processing site for review, comment, and approval prior to fabrication. Approximately one month will be required for review. Detailed criteria and procedures for receiving fuels at each site will be available from the pertinent Operations Office.
- C. All casks must be approved by the Bureau of Explosives for the shipment of the specific material involved. This approval must be evidenced by a B. of E. approval number inscribed on the container and by a copy of the request for approval along with the approval of the B. of E. made available to the AEC office administering the receiving site.
- D. Any routine shipment meeting ICC's allowable radiation requirements will be accepted.
- E. The maximum radiation limits considered acceptable for handling spent fuel shipping casks at the AEC receiving sites are 200 mr/hr at the surface of the cask and 10 mr/hr at 12 feet distance from the outside of the shipping vehicle.
- F. Casks must be readily removable from the shipping vehicle. Maximum tolerable weight of a loaded cask to be lifted from the vehicle is 75 tons.
- G. Cask must have provision for free drainage of water from all external surfaces and attachments.

- H. The use of a liquid cooling media other than water is generally not acceptable when such media can contaminate the basin water or fuel elements. Substitution of other liquid cooling media for water or the use of additives, such as antifreeze, will be considered on an individual case basis.
- I. The cask must have a readily operable drain and all internal surfaces should drain freely to it. A siphon drain is preferred since a bottom drain is more susceptible to damage and can result in the loss of the cooling water. A siphon drain must be in the body of the cask and not part of the cover.
- J. Cask design should recognize the possible use of impact wrenches in the removal of nuts and bolts. Proper consideration should, therefore, be given to the clearances necessary.
- K. Casks must be top opening. (At the ICPP and one of the SRP unloading facilities the removal of the cask lid requires outriggers at right angles to the center line of the trunnions.)
- L. All inner cask surfaces which are likely to be contacted by the coolant must be of stainless steel. All external surfaces must be accessible for decontamination. These external surfaces, including weldments, must be smooth, free of weld spatter, and crevices or pockets. Use of 300 series stainless steels on all surfaces would minimize any decontamination efforts and, therefore, decontamination costs will not be charged to the shipper if a cask of this type stainless steel is received in an acceptable condition. For any other type of material, actual costs of decontamination will be charged.
- M. Ruptured elements normally must be encapsulated. The method must be approved by the AEC processing site. Controlled release of possible fission gases should be considered.
- N. Cask design should permit withdrawal of a representative sample of the cask coolant while the cask is on the transport vehicle.
- O. The activity limit for cask cooling water is  $5 \times 10^{-8}$  beta-gamma curies/cc or \_\_\_\_\_ alpha curies/cc. (Alpha curies will be defined later.)

Appendix III

Subappendix 2

SPECIAL CASK DESIGN REQUIREMENTS AT THE ICPP

Fixed guide rails are provided in the ICPP transfer pit to protect the concrete basin structure and to facilitate handling. Dimensions between guide rails limit the overall plan dimensions of the cask to 47 1/2" x 59 1/4" for the 15-ton facility, and 18' 9" x 4' 7 1/4" for the 75-ton facility. Where dimensions of the cask proper are below the above dimensions, a base pallet or rectangular guide ring of equivalent dimension must be provided at some other appropriate elevation on the cask. Base pallet must have provision for free drainage of water.

The following details are specific for the 30,000-lb. facility:

1. Cask trunnions must be oriented in the plane of the 59 1/4" dimension to permit lateral movement of the cask at the bottom of the transfer pit in a plane at right angles to the plane of the cask trunnions.
2. Trunnions are required for handling with a two-hook crane. The crane hooks are each 2 1/2" wide and have a center line span of 54 3/4". A clearance of 11" is required below the trunnions to permit engagement of the safety lock crane hooks. To be compatible with the crane hooks the cask trunnions must have a maximum diameter of 2 1/2" be 3 3/4" in length minimum, and have a center line span of 54 3/4". The span between the outer edges of the trunnion support braces cannot exceed 59 1/4".
3. It is necessary that the cask cover be designed with outriggers which engage on retainer beams as the cask is lowered into the basin. Outriggers must have a length of 57 1/2" and must be oriented in a plane at right angles to the plane of the cask trunnions. The cask must have tapered guide pins to orient the cask cover bolt holes with respect to the cask bolts. A gasket

or O-ring must be firmly attached to either the cask or cask cover in such a manner that (in order to insure a positive seal) the pressure applied in sealing will always be perpendicular to the plane of the gasket.

4. A drain line (1/2" minimum) is required to permit drainage of water from the cavity of cask for return shipment. The drain line should extend from the bottom of the cavity up through the lead shielding and exit near the top of cask. A bottom gravity drain line is not normally considered satisfactory because of the potential for damage and loss of cooling water. A siphon drain is preferred because it is not as susceptible to damage and loss of cooling water which may result in the contamination of the cask and the carrier.
5. Fuel elements must be contained in a transfer bucket designed to fit within the cavity of the cask. Lifting hooks, bails, or trunnions are required on the bucket to permit remote removal of the bucket with elements contained therein. Normally elements will be transferred into available storage buckets at the ICPP. In event the load factor is high and/or insufficient storage buckets of the type required are available at the ICPP it may be necessary that the transfer bucket be utilized for storage also and that additional buckets be provided. The monorail transfer system and physical criticality storage barriers limit the overall dimensions of storage buckets to 11 1/4" by 15 3/4". IDO can give you drawings of yokes and buckets of various casks to illustrate equipment that has been found satisfactory for this service.
6. The maximum cask height may not exceed 9 feet. The exact limit is dependent on the elevation of the trunnions.

The following are specific for the 75-ton facility:

1. Cask trunnions must be oriented in the plane of the 18' 9" dimension to permit lateral movement of the cask at the

- bottom of the transfer pit in a plane at right angles to the plane of the cask trunnions.
2. Trunnions are required for handling with a two-hook load bar. The load bar hooks are  $5 \frac{7}{8}$  inches wide and have a center line span of 17 feet  $10 \frac{3}{8}$  inches. A clearance of 15 inches is required below the trunnions to permit engagement of the load bar hooks. To be compatible with the load bar hooks the cask trunnions must have a maximum diameter of 6 inches, be a minimum of  $7 \frac{1}{2}$  inches in length, and have a center line span of 17 feet  $10 \frac{3}{8}$  inches.
  3. The positioning of the cask trunnions must take into consideration the 4 feet  $7 \frac{1}{2}$  inch distance between the bottom of the load bar and the top edge of the load bar hooks.
  4. The length of the two outriggers on the cask cover is 5 feet 9 inches. They must be oriented symmetrically on the cask cover in the direction of the 4 foot  $7 \frac{1}{4}$  inch direction. The distance between the inside edges of the outriggers must be 8 feet  $2 \frac{1}{2}$  inches with a maximum tolerance of ( $\pm 1'' - 1/4''$ ). The cask must have tapered guide pins to orient the cask cover bolt holes with respect to the cask bolts. A gasket must be firmly attached to either the cask or cask cover in such a manner that (in order to insure a positive seal) the pressure applied in sealing will always be perpendicular to the plane of the gasket.
  5. A drain line (1" minimum) is required to permit drainage of water from the cavity of cask for return shipment. The drain line should extend from the bottom of the cavity up through the lead shielding and exit near the top of cask. A bottom gravity drain line is not normally considered satisfactory because of the potential for damage and loss of cooling water. A siphon drain is preferred because it is not as susceptible to damage and loss of cooling water which may result in the contamination of the cask and the carrier.

6. The maximum cask dimensions are 7 feet high, 4 feet 7 1/4 inches wide and 18 feet 9 inches long. The exact height limit is dependent on the elevation of the trunnions.
7. Fuel elements must be contained in a magazine clip designed to fit within the cavity of the cask. Lifting hooks, bails, or trunnions are required on the magazine clip to permit remote removal of the magazine clip with elements contained therein. Normally elements will be transferred into available storage magazine clips at the ICPP. In event the load factor is high and/or insufficient magazine clips of the type required are available at the ICPP it may be necessary that the magazine clip be utilized for storage also and that additional magazine clips be provided.

Appendix III

Subappendix 3

CASK ACCEPTANCE CRITERIA  
RECEIVING BASIN FOR OFF-SITE FUELS  
SAVANNAH RIVER PLANT

A. Shipments

1. Shipments to the Savannah River Plant can be routinely made by rail or motor freight. It is possible to obtain barge service up the Savannah River to SRP, but special arrangements would have to be made between the shipper and carrier, as transportation of this type is not normally available. Further complications would arise at SRP, as there are no permanent dockside facilities for unloading. Special handling would be necessary for water shipments of this type.
2. Agreement between the shipper and the Savannah River Operations Office is required on all shipping schedules. Further, the Savannah River Operations Office must be notified in advance of each shipment, giving such information as
  - (a) Method of shipment
  - (b) Arrival date
  - (c) Number of casks
  - (d) Cask contents (fuel data)
    - (1) Total irradiation time
    - (2) Date irradiation ended
    - (3) Heat evolution of each assembly in shipment
    - (4) Power generated in each assembly (KW/Kg) during irradiation
  - (e) \*Activity of primary coolant in curies
  - (f) \*Cask outside radiation and contamination level
  - (g) Other information as required

\*Information should be transmitted immediately after determination.

3. F. O. B. Points

- (a) Rail-Dunbarton, South Carolina
- (b) Truck-Dunbarton, South Carolina
- (c) Water-Charleston, South Carolina or Savannah, Georgia;  
transfer by rail or truck to Dunbarton, South Carolina

4. Fuel will not be accepted at the Savannah River Plant until 90 days after final nuclear irradiation.

5. Any routine shipment meeting ICC's allowable radiation requirements will be accepted, subject to the other provisions of this Appendix III.

B. Coolant Medium

This cask acceptance criteria is based upon the use of water as a primary coolant. Substitution of any cooling medium for water or the use of additives in the water, such as anti-freeze or salt solutions, will be considered on an individual case basis.

C. Radioactive Contamination

1. External Contamination

Immediately before each shipment, representative parts of the cask are to be surveyed for external contamination by wiping an area of about 100 sq. cm. with clean filter paper, applying moderate finger pressure, and measuring the contamination on the filter paper by means of standard counting techniques for both beta-gamma and alpha activities. The cask is not to be shipped if the contamination measured in this way exceeds 4000 d/m per 100 sq. cm. of beta-gamma or 500 d/m per 100 sq. cm. of alpha activity. The filter paper must be dry when being counted so as not to obscure alpha activity.

2. Internal Contamination

Upon removal of a shipping cask from a loading basin, the basin water is to be flushed from the cask using clean water. The cask water is then to be sampled and the activity determined

by a mutually acceptable method.

The activity of shipping casks will be determined at SRP before opening the cask by recirculating the coolant for a sufficient period of time to accurately determine the activity of the coolant. If the total beta-gamma activity of the coolant is significantly greater than that determined at the shipping point, failure of one of the elements in the cask will be suspected and capsulation of the fuel assemblies may be required. If exposure of source or special nuclear material (SSNM) is suspected, the cask will be flushed in an attempt to reduce the activity and by various techniques, including laboratory analyses, an attempt will be made to determine whether the activity is actually caused by fission or corrosion products. Shipments not containing exposed SSNM but in which the cask coolant is contaminated to greater than one curie may require special handling.

D. Surface Temperatures

Cask designs that permit attainment of cask surface temperatures which present a handling hazard must also incorporate designs that permit safe handling techniques. Cost of provision of special handling tools must be borne by the shipper.

E. Criticality

Fuel contained in a cask shipped to SRP must be critically safe when submerged in water with the cask lid removed. The fuel elements must be packaged in the cask so that they can be removed in water without resulting in a criticality hazard. In addition, consideration must be given to the possibility of the cask coming into close proximity to other casks in transit and in the receiver's yard.

The shipper must submit for review and approval the basis for determination that the cask is critically safe. Data obtained from any critical experiments that have been performed must be included.

F. SRP Receiving Basins for Off-Site Fuels (RBOF)

1. General

Casks are handled in two cask unloading basins serviced by a 100 ton crane. The crane is of twin hook design, with an adapter to convert it to a single hook crane, with 27 feet maximum clearance to the palm of the hooks in the Basin area. Clearance to the palm of the hooks at the car unloading spot is 33 feet.

2. Cask Dimensional Limitations

The two water-filled cask unloading basins are rectangularly shaped, 13 feet wide and 27 feet long. The floor level in each basin is at a water depth of 28 feet and in addition, each basin contains a pit 9-1/2 feet in diameter and a water depth of 44 feet.

Cask assemblies are lowered into the basins and placed on the floor at the proper depth. The cask lid is removed and stored in the basin or in an external pit.

The hoists on the 100 ton, twin hook crane operate independently or as a single unit. The span between the centerline of the hooks can be varied from a minimum of 8' 0" to a maximum usable span of 22' 9". (Actual maximum span is 23' 6".)

(a) Cask Limitations

	<u>Horizontal Cask (4)(5)</u>	<u>Vertical Cask (4)(5)</u>
Maximum loaded cask weight	100 ton	100 ton
Crane hook spacing minimum	8' 0"	8' 0"
maximum	22' 9"	22' 9"
Maximum height cask body (1)	14'	- - -
Maximum length, including trunnions (2)	24' 9"	33' -X
Maximum width cask	9' 0"	- - -
Maximum diameter	- - -	8' 10"
Minimum clearance under trunnions (3)	See Dimension "D" below	

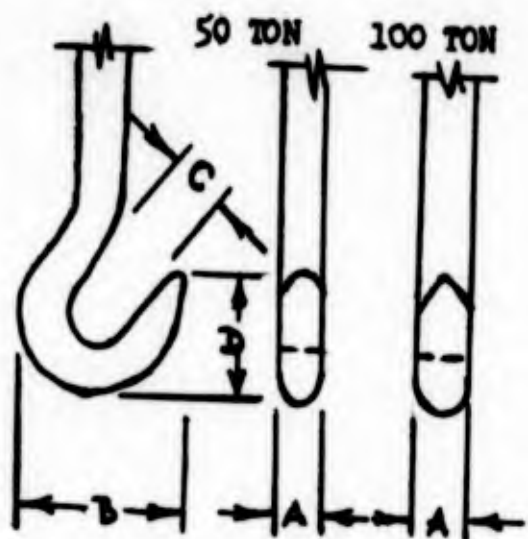
- (1) Includes any projections, such as dowel pins. Also presumes element removal in horizontal position.
- (2) X = Maximum fuel element length in feet.
- (3) For engagement of crane hooks.
- (4) Any variation from these limits will be handled on an individual basis.
- (5) The terms horizontal and vertical refer to the disposition of the long axis during underwater unloading. All casks are assumed to be top opening for unloading.

(b) Crane hook dimensions (50 ton)

- |  |         |
|--|---------|
| A. Width                               | 6-1/4"  |
| B. Depth through palm                  | 20-1/2" |
| C. I. D. of throat                     | 7"      |
| D. Distance from tip to bottom of hook | 12-1/2" |

(c) Crane Hook dimensions (100 ton)

- |  |        |
|--|--------|
| A. Width                               | 10"    |
| B. Depth through palm                  | 35"    |
| C. I. D. of throat                     | 9-1/4" |
| D. Distance from tip to bottom of hook | 28"    |



3. Fuel Element Packaging

- (a) Fuel element packages within the cask vary with the nature of the elements and the cask design. The weight of any fuel package to be removed from the cask as a unit and transported under water must not exceed three tons. The size of the fuel element package is limited to:

Circular units, max. diameter of 28 inches. Square units, max. size is 24 inches square. Rectangular units, max. width of 28 inches and max. diagonal of 34 inches. Vertical length of any unit, 17-1/2 ft.

- (b) Sodium bonded fuels must be encapsulated in gas filled stainless steel capsules prior to shipment. The capsule must be provided with a vent connection suitable for connecting, by means of flexible tubing, the capsule to a nitrogen manifold in the SRP receiving facility. Approval of the capsule design must be secured from the Savannah River Operations Office prior to shipment.

G. Cask Design

- 1. In addition to being dimensionally compatible with the cask unloading basins and handling equipment, cask design must include the following features:
  - (a) The cask must be equipped with tapered dowel pins or other positioning devices to guide the lid into position as the lid is replaced under water. These guides are required to prevent damage to the hold-down bolts or other parts of the cask.
  - (b) Provision for free drainage from all external surfaces and attachments.
  - (c) A means of sampling and flushing the cask primary coolant with the cask closed, while cask is on the transport vehicle. This design feature must include valves that isolate cask coolant from the cask connection. If a secondary coolant is used, a sampler tap and isolation valves must be provided.
  - (d) Means shall be provided for measurement of the maximum primary coolant temperature or cask cavity wall temperature at any time, by use of a portable readout instrument if desired.

- (e) A siphon drain line or a drain line to remove water from cask for return shipment.
  - (f) Casks must be top opening.
  - (g) If cask trunnion design is not compatible with the limits and dimensions given in section F, a yoke must be furnished to handle the cask with the appropriate hook (50 or 100 ton). Such yokes are required to be rigid and must be designed so that the specific static stress does not exceed  $1/5$  of the ultimate strength of a member, (Refer to Specification No. 61 of the Electrical Overhead Crane Institute, Inc., No. 1 Thomas Circle N. W., Washington 5, D. C.). Also, yokes must be designed for vertical storage as they will be engaged and disengaged under water. It is necessary that three copies of the complete stress analysis of the yokes be furnished to the Savannah River Operations Office for review.
2. All inner cask surfaces which are likely to be contacted by the coolant must be of stainless steel or other acceptable non-corrosive metal. All external surfaces must be accessible for decontamination. These external surfaces, including weldments, must be smooth, free of weld spatter, and crevices or pockets. Use of 300 series stainless steel on all surfaces would minimize any decontamination efforts, therefore, decontamination costs will not be charged to the shipper if a cask of this type stainless steel is received in an acceptable condition. For any other type of material, the full cost of decontamination will be charged.
  3. Cask design must be such as to permit cask handling operations prior to unloading; such as cask transfers and bolt removal, to be accomplished with a maximum total exposure of 24 mr to operating personnel at the RBOP facility.
  4. Cask lifting devices must be a part of the cask proper and not the cask lid. Cask lids must contain a lid lifting eye and the lids will be handled by a single crane hoist or with an adapter yoke. No slings will be used for handling casks or cask lids.

5. All casks must be provided with some means to prevent over-pressurizing and some means of containment for liquid release.
6. The outer edge of the bottom of the cask must be given at least a 1/2-inch radius to prevent gouging the stainless steel floor lining in the RBOF basins.

H. Drawings

To insure compatibility with existing handling facilities, it is necessary that six complete sets of design drawings of the cask and components and method of attachment to the shipping vehicle proposed for use in shipment of fuel elements be transmitted to Savannah River Operations Office. Approximately one month will be required for review.

I. Approval by Bureau of Explosives

All casks must be approved by the Bureau of Explosives for the shipment of the specific material involved. This approval must be evidenced by a B. of E. approval number inscribed on the container and by a copy of the request for approval along with the approval of the B. of E. made available to the Savannah River Operations Office.

J. Receipt of Solid Radioactive Wastes

No contaminated waste materials which are not an integral part of the fuel assembly will be received at SRP for disposal unless specifically arranged for and agreed to prior to shipment.

K. Change of Processing Site

In the event that a change of the chemical processing site (to a site other than the Savannah River Plant) is effected by the Commission, the criteria for acceptance of cask shipments at such new site shall be substituted by the Commission for this Appendix III. Such substitution shall be effected without any adjustment in Contract charges notwithstanding any added costs to the Company that may result from such change of site. Such change shall not effect the determination of an "assumed shipping schedule" in accordance with this Contract.

Appendix IV

COMMON RADIAC FIELD SURVEY INSTRUMENTS

The purpose of this appendix is to briefly introduce the reader who may be unacquainted with radiac equipment to the instruments and devices which will most likely be used by health physics personnel or worn by loading and air crews in the air transport of nuclear reactor and radioactive materials. Equipment descriptions are excerpted from Ref. 27.

The term radiac comes from the words Radioactivity, Detection, Indication, And Computation. Devices used to detect and indicate radioactivity are called radiacmeters. Those radiacmeters which indicate dose rate or the intensity of radiation are called rate meters and those which integrate the dose rate over a period of time are called dosimeters. The term radiac set refers to a set which contains the radiacmeter, carrying case, auxiliary equipment, and spare parts.

All of the instruments suggested here for use in the air transportation of nuclear reactor and radioisotopic materials are Air Force standard items (i. e., an item which has been certified as meeting an established need and determined to be suitable for Air Force use). Normally, there will be only one item of equipment in the standard status for each specific Air Force need or use.

The following radiacmeters are recommended for the uses discussed:

USAF RADIOLOGICAL HEALTH LABORATORY  
IN-LINE FILM BADGE HOLDER

Figure 21 shows the film badge holder normally issued by the USAF Radiological Health Laboratory to field units, for the purpose of detecting the beta, gamma and X-radiation exposures personnel have received. Two film packets, one to record the monthly dose and one to record the quarterly dose, are contained in the holder. A neutron film packet can be substituted for the monthly film for personnel exposed to low-level neutron doses.

Photographic emulsions are used in dosimeter films to measure ionizing radiation dose. When light, other electromagnetic waves, or beta

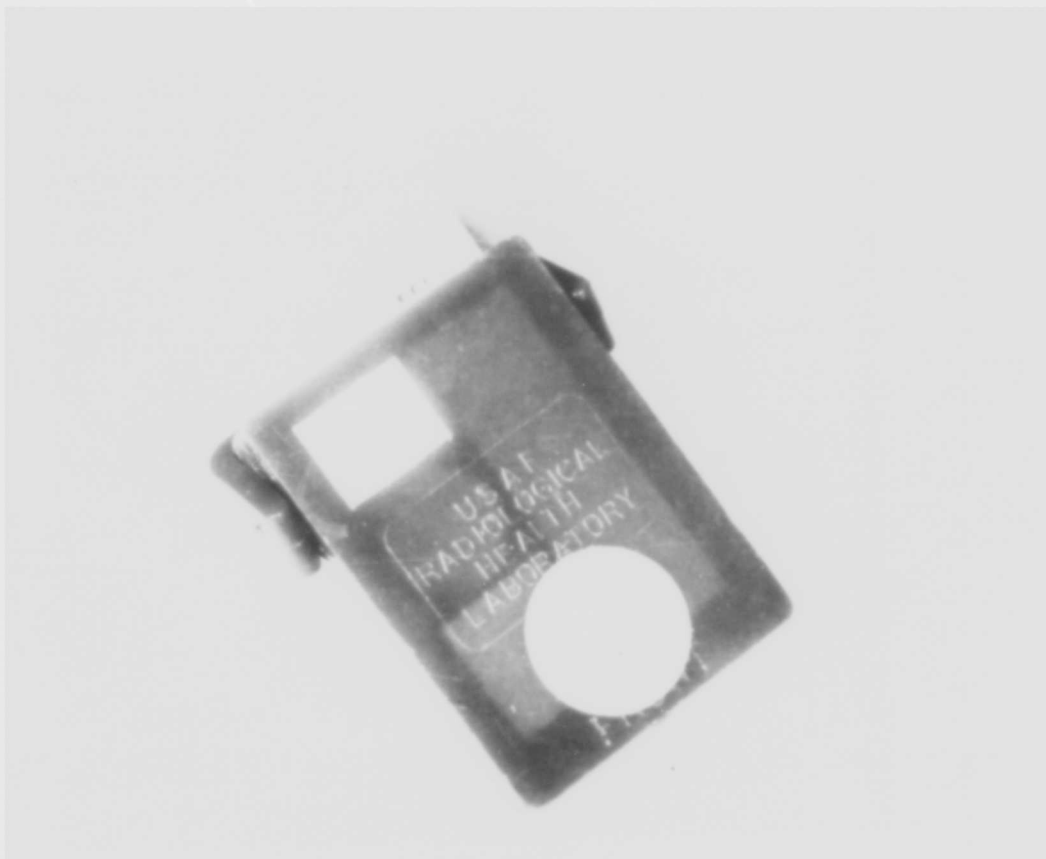


Figure 21. USAF Radiological Health Laboratory in-line film badge holder

particles strike the emulsion some of the silver halide atoms of the emulsion are reduced to free silver atoms which constitute the so-called latent image. The image is developed by a suitable reducing agent (developer) and a fixing solution is used to dissolve the residual silver halide grains. The degree of darkening achieved depends upon the emulsion characteristics and processing conditions as well as the exposure to radiation. This degree of darkening is measured in terms of its optical density and is proportional to the energy of the radiation and the radiation dose received by the film. The optical density is determined by the use of a photographic densitometer and the dose is determined by comparing the reading with controlled densities produced by similar radiation of known energy and dose. To overcome or circumvent the

problem of photon energy dependence of film emulsion, a system of filters or absorbers are incorporated into the film badge holder which contains the film packets.

Nuclear reactions with the nitrogen and hydrogen content of the nuclear track emulsion permit the measurement of neutron exposures. The use of the  $N^{14} (n, p)C^{14}$  reaction of the nitrogen in the nuclear track emulsion permits the indication of thermal neutron dose with the same range of track density as is produced by hydrogen recoils by a fast neutron. The track, to be recognizable, must have at least three silver grains. Tracks are counted by magnifying and projecting the film image on a screen using a microprojector.

### TECHNICAL CHARACTERISTICS

<b>Detector Type:</b>	DuPont film packet 556 (2 Ea.) containing 508 and 834 emulsion films. (Kodak type NTA neutron film can be substituted for one DuPont film packet for personnel exposed to low level neutron doses.)
<b><u>Radiations Detected:</u></b>	Gamma and X radiation. Beta particles having an energy greater than 150 kev. Neutrons when special film packet is used.
<b><u>Sensitivity:</u></b>	
Gamma or X-ray energies	
31 kev Range:	5 mr - 100 r
124 kev Range:	5 mr - 100 r
1.24 Mev Range:	50 mr - 700 r
Beta Radiation:	40 mrad - 500 rads
Neutron dosimetry:	20 mrads to 10 rads
<b><u>Holder:</u></b>	
Capacity:	2 film packets.
Composition:	Plastic (Cellulose acetate butyrate)
Metal Filters:	Cadmium, tungsten and aluminum

Calibration:

Low Energy Gamma  
and X-radiation:

R-meter and X-ray machine

High energy gamma:

Ra-226 and Co-60 sources

Beta-radiation:

Uranium source

Neutrons:

Po-Be source

Accuracy:

For  $\beta$  ,  $\gamma$  & X rays:

From  $\pm 50\%$  at lowest readable dose  
to  $\pm 10\%$  for dosages in the rad.

For neutrons:

Within a factor of 2 for exposures in  
the 100 mrem/week range. Accuracy  
increases with increase in exposure  
dose.

Precautions:

Dosimetry film packets should be stored  
in an area as remote as practicable from  
the radiation level and away from chemi-  
cals, such as formaldehyde, which cause  
fogging and sensitization of the film.  
Film stocks must be stored at tempera-  
tures less than 75°F (preferably 65°F)  
and should not be subjected to stresses  
such as pressure from stocks of  
materials or tightly wound rubber bands,  
which result in sensitization of the film.  
Dosimeter film may be used during the  
indicated month of expiration but not  
thereafter. A "control" film badge must  
be used for each group of monitoring  
films submitted for processing in order  
that the background radiation to which  
personnel monitoring film badges are  
exposed may be estimated for each  
monitoring site. The "control" film

badge must be placed in the same minimum radiation area in which personnel-monitoring film badges are stored when they are not being worn.

Dimensions of Film Badge:

Length:	2-1/2 inches
Width:	1-11/32 inches
Thickness:	5/16 inch
Weight of Film Badge:	1-1/4 ounces

LOGISTIC AND MISCELLANEOUS INFORMATION

Federal Stock Number:

Issued by USAF Radiological Health Laboratory, Attn: HWR, Wright-Patterson AFB, Ohio, through base medical services of the installation concerned.

Approximate Cost:

\$1.50

Specification:

Development Agency:

USAF Radiological Health Laboratory

USAF Status:

Standard since mid-1961

Replacement Data:

References:

AFR 161-11  
AFR 160-31  
AFR 160-132

IM-9(C or D)/PD & IM-135/PD

The IM-9 (C or D)/PD or IM-135/PD, suggested as the proper instruments for self-reading personnel dosimetry, are shown with their charger in figure 22. They are designed to measure cumulative radiation exposure to gamma and X radiation up to 200 milliroentgens for the IM-9 (C or D)/PD and up to 5 roentgens for the IM-135/PD. The dosimeters are to be used for

estimating exposures received during operations and are not intended to replace or supersede film badge dosimetry.

These radiacmeters have a built-in string electrometer and ion chamber. A PP-1578/PD charger is used to impress a charge on the ion chamber. A zero position on the built-in scale indicates that the dosimeter is fully charged. Radiation passing through the chamber will cause the charge to leak off in proportion to the amount of radiation and move the electrometer string upscale, accordingly.

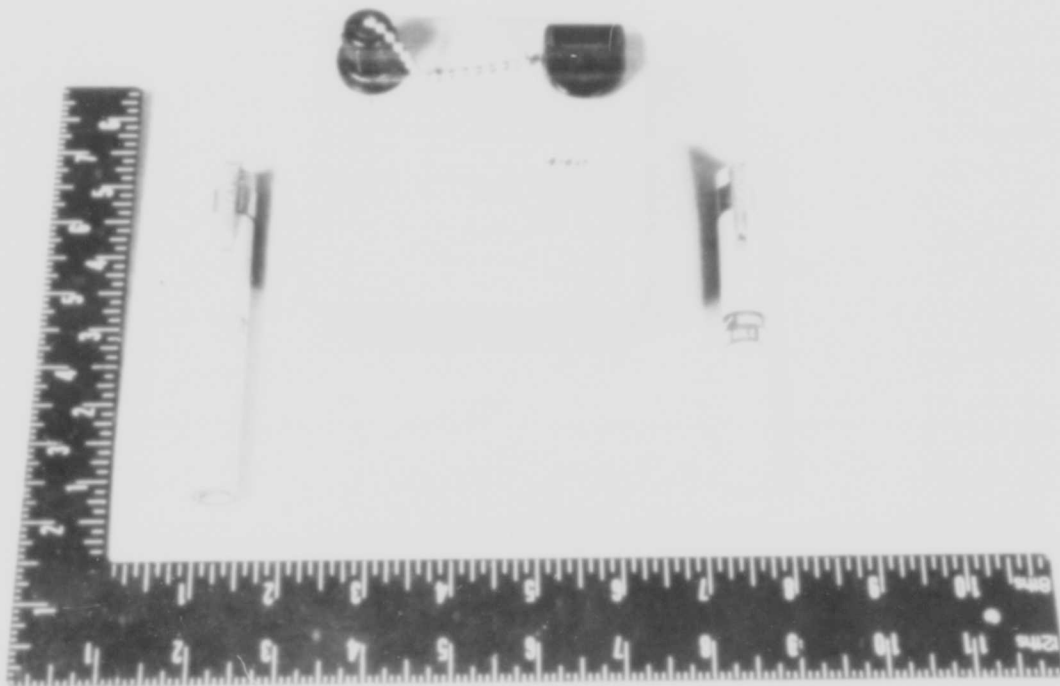


Figure 22. IM-9 (C or D)/PD and IM-135/PD self-reading pocket dosimeters with charger

#### TECHNICAL CHARACTERISTICS

Detector Type:

Ion chamber operation in the ionization chamber region of the pulse height curve.

Radiation Detected:

Gamma and X rays

Sensitivity:

0 to 200 mr for IM-9 (C or D)/PD

0 to 5 r for IM-135/PD

Calibration:

Accuracy:

±5%

By:

Radiac Calibration Set AN/UDM-1A  
(FSN 6665-765-1048) or Cobalt-60  
Calibration Source (FSN 6665-515-  
6071 and FSN 6665-801-2611)

Overall Accuracy:

±15% of true dose at any point on the  
scale. Not affected by changes in tem-  
perature. Energy dependence is ±15%  
from 80 kev to 2 Mev or greater.  
Ionization chamber is hermetically  
sealed and is therefore not affected by  
humidity nor altitude changes.

Temperature and Energy  
Dependence: and Effect of  
Humidity and Altitude:

Power

Requirements:

160 to 180 volts charging voltage

Dimensions

Length:

IM-9  
3-5/8 inches

IM-135  
4-3/8 inches

Diameter:

7/16 inch

1/2 inch

Weight:

1/2 ounce

1 ounce

LOGISTIC AND MISCELLANEOUS INFORMATION

Federal Stock Numbers

IM-9 (C)/PD:

FSN 6665-263-3941

IM-9 (D)/PD:

FSN 6665-526-8643

IM-135/PD:

FSN 6665-621-0417

Approximate Cost

IM-9(C)/PD:

\$38.00

IM-9(D)/PD:

\$20.00

IM-135/PD:

\$21.00

Specification:

IM-9 (C or D)/PD: Mil-R-10059  
IM-135/PD: Mil-R-19935

Development Agency:

Bu Ships (SWRB)

USAF Status

IM-9 (C or D)/PD: Standard since 19 Aug 1954  
IM-135/PD: Standard since 18 Feb 1960

Equipment Allowance

ECL 459: Set - Chemical, Biological and Radiological Defense Equipment

Documents:

ECL 449: Set - Weather Reconnaissance Radiological Detection

Reference:

T.O. 11H4-6-1-1

AN/PDR-27J

Radiac Set AN/PDR-27J (an AN/PDR-27A is shown in figure 23), the most recent model of the AN/PDR-27 ( ) series, contains a Geiger-Mueller type radiacmeter capable of measuring gamma radiation and detecting beta particles having an energy greater than 50 kev and detecting alpha particles having an energy greater than 5 Mev. G-M tubes have lead shields to assist in energy independence. The principle of operation is based upon the fact that when G-M tubes are exposed to a radiation field, they produce short duration d-c voltage pulses at an average repetition rate proportional to the average radiation field intensity in the vicinity of these tubes. This radiacmeter will saturate and read zero in high radiation fields.

This radiac set is suggested for the direct beta-gamma surveying operations required in the transport of irradiated reactor fuel elements, radioactive wastes, contaminated tools and components (perhaps) and beta-gamma emitting radioisotope generator units. For detection of beta radiation, a beta shield on the end of the larger component of the probe must be moved aside, thus exposing a 0.0005 inch thick mica end-window. Beta-gamma radiation may be detected with the end window G-M tube over the two

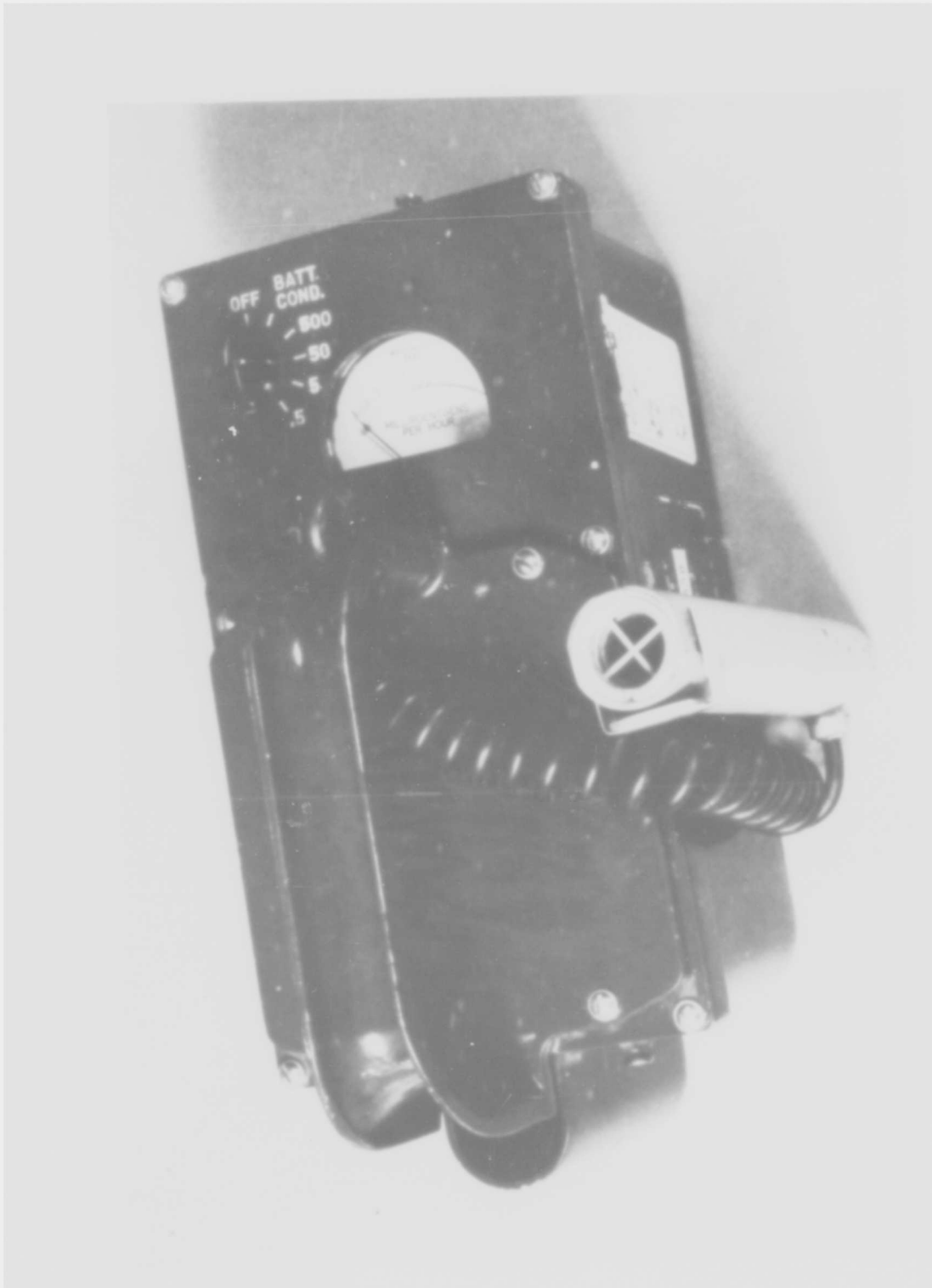


Figure 23. AN/PDR-27A radiac set

more sensitive ranges. Only gamma radiation may be detected with the small G-M tube over the two less sensitive ranges. A plastic tube containing 7 micrograms of radium is furnished with the set to check the instruments' ranges for response to radiation.

An instrument presently designated as the IM-189 (XVI) will shortly be available. It will ultimately replace the AN/PDR-27J, the AN/PDR-39 and 39A, and the AN/PDR-43 Radiac sets. The IM-189 (XVI) will be a superior instrument for the applications discussed herein, and should it be available, should be used in lieu of the AN/PDR-27J. Technical characteristics of the AN/PDR-27J follow:

#### TECHNICAL CHARACTERISTICS

<u>Detector Type:</u>	Self-quenching Geiger-Mueller tubes operated at 700 volts potential. One tube has 0.0005-inch thick mica end-window.
<u>Radiations Detected:</u>	Measures gamma and detects beta particles having an energy greater than 50 kev and alpha-particles having an energy greater than 5 Mev.
<u>Sensitivity:</u>	0.5 to 500 mr/hr in four operating ranges and color-coded scales: 0 to 500 mr/hr (yellow) 0 to 50 mr/hr (white) 0 to 5 mr/hr (green-yellow) 0 to 0.5 mr/hr (light blue)
<u>Calibration</u>	
Accuracy:	±5%
By:	Radiac Calibrator Set AN/UDM-1A (FSN 6665-765-1048) or Cobalt-60 Calibration Source (FSN 6665-515-6071 and FSN 6665-801-2611)

Overall Accuracy;

Temperature and Energy

Response; and Effect of

Humidity and Altitude:

± 30% for gamma radiation from 10% full scale on each range over a temperature range of -40°F to 122°F. A significant drop in response is noted after a few hours of operation below -40°F, unless batteries are removed from instrument and housed on the body of person using instrument. Energy response varies with ± 20% from 80 kev to 2 Mev. G-M tubes are sealed and not subject to altitude changes. Humidity effects are controlled by sealing the instrument case.

Power

Requirement:

6 Ea. B-A 30 dry cell batteries 1-1/2 volts each, connected in series.

Operating Period:

40 hours of continuous operation at 77°F.

Dimensions of Radiacmeter

Length:

11-9/16 inches

Width:

5-inches

Height:

7-5/8 inches

LOGISTIC AND MISCELLANEOUS INFORMATION

Federal Stock Number:

6665-543-1435 (No Model J in AF Inventory)

Approximate Cost:

\$550.00

Specification:

R-3514

Development Agency:

Bu Ships (SWRB)

USAF Status:

Standard since 4 Oct 60

Replacement Data:

AN/PDR-27J is the most recent model of the AN/PDR-27 ( ) series.

Equipment Allowance Documents:

ECL 768: Set-Explosive Ordnance Disposal

Reference:

NAV Ships 93218

Set Comprises:

1 Ea. Case, Radiac Set  
1 Ea. Radiacmeter  
1 Ea. Detector  
1 Ea. Headset  
1 Ea. Harness  
1 Ea. Radioactive Test Sample  
3 Ea. Spare Tubes  
2 Ea. Instruction Books

Dimensions of Radiac Set Case

Length: 17 inches  
Width: 5-1/2 inches  
Height: 8-1/2 inches

Weight of Radiac Set:

20.5 pounds

PAC-1S (AN/PDR-60) Radiac Set

The AN/PDR-60 Radiac Set, shown in figure 24 is recommended for the monitoring of alpha contamination. It contains an alpha scintillation radiac meter capable of measuring radioactive material emitting alpha particles with an energy greater than 4.1 Mev. Alpha particles having energies as low as 3.4 Mev can be counted through one end of the probe due to a thinner window thickness at that end. The AN/PDR-60 is more robust while the AN/PDR-54, which is most similar to it, is more sensitive, and so the former is recommended for field use while the latter is recommended for laboratory use.

The principle of operation involves the transfer of energy from radiation to a silver-activated zinc sulfide phosphor which responds only to the most densely ionizing radiation such as that produced by an alpha particle. A very low-level light pulse is given off for each alpha particle that strikes the scintillation phosphor on the 59-square-centimeter open area face of the

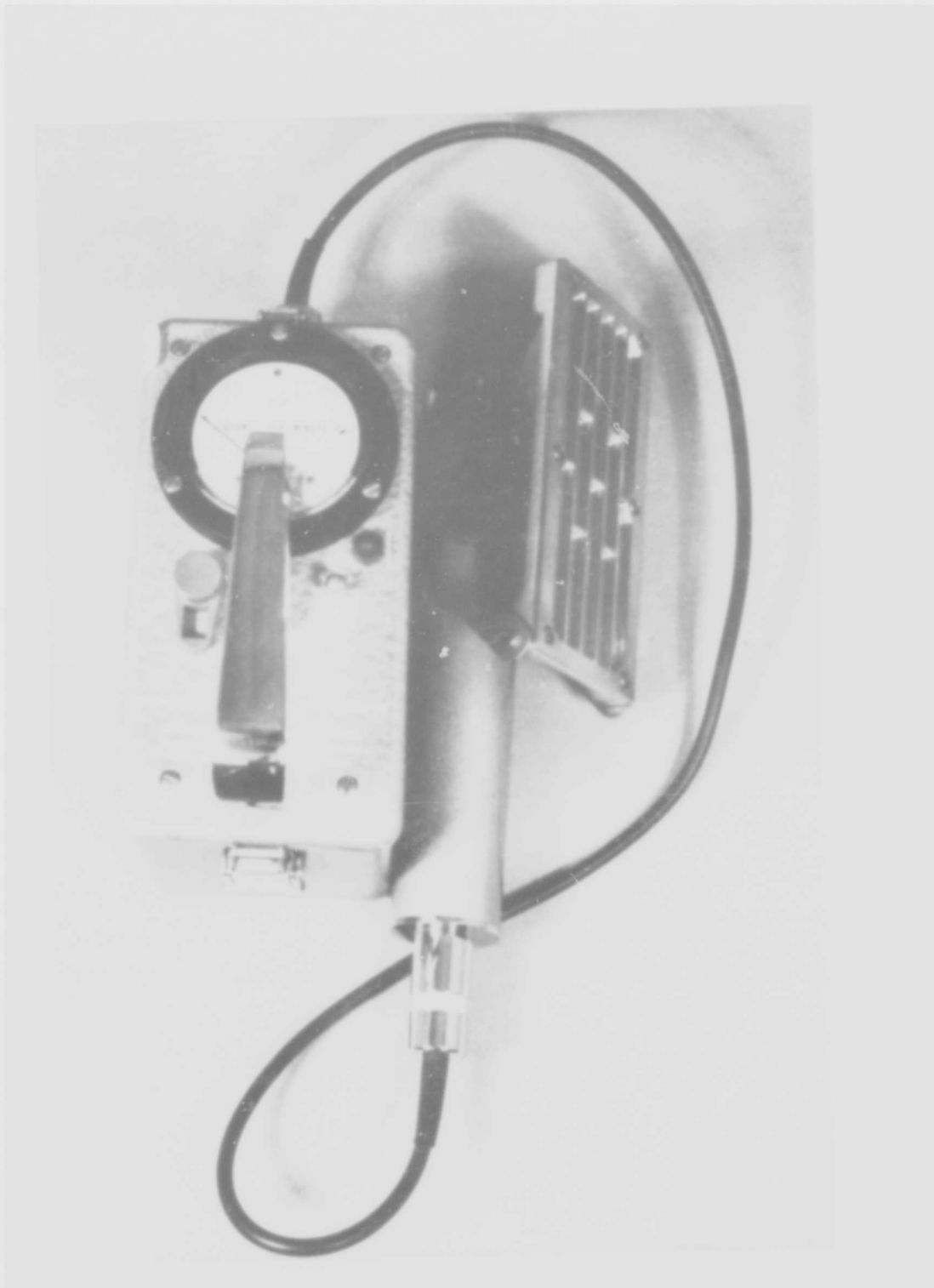


Figure 24. PAC-1S or AN-PDR/60 radiac set

detector probe. The light is transmitted optically to a photomultiplier and then to an amplifier trigger in which all pulses above a certain level are amplified. The meter reading is proportional to the rate of alpha particles striking the scintillation phosphor.

A  $\text{PuO}_2$  check source is clipped to the rear end of the detector probe face.

### TECHNICAL CHARACTERISTICS

#### Detector Type:

Silver-activated zinc sulfide scintillation phosphor probe face having a free area of 59 sq cm. The probe contains a 1-inch diameter photoelectric cell (photomultiplier tube) and a light gathering lens system. 1250-volt d. c. power is applied to the anode and dynode network of the photomultiplier tube. The probe has a non-uniformity factor which normally is less than  $\pm 12\%$  of the median of a source reading. The scintillation screen is covered with  $0.93 \text{ mg/cm}^2$  of mylar and  $0.37$  to  $0.74 \text{ mg/cm}^2$  of dutch leaf (aluminum). Design of probe face plate permits a minimum average distance of  $7/64$  inch between window and source

#### Radiations Detected:

Alpha particles having energies greater than 3.4 Mev can be counted at one end of the probe face. All alpha particles having energies greater than 4.1 Mev are counted with the probe face placed in contact with the surface being monitored.

Sensitivity:

Four range scales are used as follows:

C-2,000 cpm per 59 sq cm

C-20,000 cpm per 59 sq cm

C-200,000 cpm per 59 sq cm

C-2,000,000 cpm per 59 sq mc

NOTE: 100,000 cpm per 59 sq cm probe area on smooth, dry, horizontal surface under average field conditions is equivalent to approximately 310 micrograms of plutonium-239 per square meter or 19.1 microcuries of alpha activity per square meter.

Calibration

Accuracy:

$\pm 10\%$

By:

Secondary alpha calibration standards,  
FSN 6665-767-7497

Overall Accuracy;

$\pm 20\%$  with probe in contact with surface

Temperature and Energy

being monitored. Will operate from

Response: and Effect of

$-40^{\circ}\text{F}$  to  $+130^{\circ}\text{F}$ . Will hold  $\pm 20\%$

Humidity and Altitude:

of calibration from  $-10^{\circ}\text{F}$  to  $+120^{\circ}\text{F}$ .

With probe face 5/8 inch from the source only 15% of Pu-239 alpha contamination and 5% U-238 alpha contamination are detected. Not affected by humidity or altitude changes. Probe face must be dry to detect alpha.

Power

Requirements:

4 Ea. Yardney LR5 rechargeable wet cell batteries.

Operating Period:

200 hours continuous operation at room temperature. Battery life is shortened by very low or very high temperature operation.

Dimensions of Radiacmeter

Length:

9 inches

Width: 3-15/16 inches  
Height: 5-3/8 inches  
Weight of Radiacmeter: 5-1/2 lbs.  
(including batteries)

LOGISTIC AND MISCELLANEOUS INFORMATION

Federal Stock Number: 6665-580-3020  
Approximate Unit Cost: \$876.00  
Specification: - - - -  
Development Agency: Commercial (SWRB)  
USAF Status: Standard since 26 Sep 59  
Replacement Data: Supplements PAC-2GA gas flow proportional alpha counter  
Equipment Allowance Documents: ECL 459: Set - Chemical, Biological and Radiological Defense Equipment.  
ECL 906: Set - Environmental Health.  
ECL 768: Set - Explosive Ordnance Disposal  
Reference: T.O. 11H4-4-2-31  
-32  
-33  
-34  
AFSWC-TN-59-27  
Set Comprises: 1 Ea. Carrying Case  
1 Ea. Alpha Scintillation Counter  
4 Ea. Face Plates for Probe  
1 Ea. Bottle of Black Lacquer,  
1/2 oz. (Probe face Repair Kit)  
1 Ea. Battery Filling Set  
1 Ea. Operating Manual

Dimensions of Radiac Set Case

Length:	22-1/4 inches
Width:	14-1/4 inches
Height:	7 inches
Weight of Radiac Set:	15-1/2 pounds

Appendix V

CALCULATIONS FOR THE TERMINAL VELOCITY RANGE OF  
THE PM-1 IRRADIATED FUEL ELEMENTS CASK

The PM-1 cask has roughly the following dimensions:

height	68 in.
diameter	42 in.
weight	30,000 lb.

An exact value of the terminal velocity of such a cask is dependent upon the initial conditions of injection into the atmosphere (i. e., the altitude and especially the exact configuration including any attached aircraft debris and the initial angular momentum imparted to the package). It is possible to obtain a range of values within which the free-falling terminal velocity of the cask must lie. One of the endpoints of the range will be determined by assuming the cask falls "end-on." The other end point (maximum or minimum) velocity is obtained by assuming the cask, in stable free fall, presents its side to the opposing air flow ("side-on"). Values for an oscillating or rotating cask should lie between these two extremes.

The terminal velocity is defined as the point at which the aerodynamic drag force is just equal to the gravitational attraction force exerted by the earth's gravitational mass upon the cask. It is the maximum velocity of the free-falling object can achieve in the real atmosphere. Stated mathematically

$$\text{drag force} = \frac{\rho V^2}{2g} C_d A$$

and

$$\text{gravitational force} = W$$

Then at terminal velocity the following identity exists:

$$\frac{\rho V^2}{2g} C_d A = W$$

- where
- $\rho$  = the density of air
  - $g$  = the gravitational acceleration value
  - $V$  = the velocity of the cask
  - $C_d$  = the drag coefficient of the cask
  - $A$  = the cross sectional area presented by the cask

$C_d$  is a function of the Reynolds number and has been taken as given in Figure 130 (for end-on flow) and Figure 128 (for side-on flow), (reference 28).

The Reynolds number is defined as:

$$N_{re} = \frac{\rho VD}{\mu} \quad (\text{dimensionless})$$

- where
- $D$  = characteristic dimension (here taken to be the diameter)
- and
- $\mu$  = dynamic viscosity of the air

For the purposes of evaluation  $\mu$ ,  $\rho$ ,  $g$ , and  $W$  sea level, standard atmospheric pressure and temperature are assumed. This will give the best values of the terminal velocity range for terrestrial impact of the cask.

For the case of end-on free-fall,  $C_d$  is constant in the appropriate range of  $N_{re}$ . This leads to a rather well defined determination of the terminal velocity in this mode, which was calculated to be approximately 1480  $\frac{\text{feet}}{\text{sec}}$ .

For the side-on mode  $C_d$  is not constant and so an iterative type calculation was required. The terminal velocity value obtained here was approximately 1600  $\frac{\text{ft}}{\text{sec}}$ .

One may conclude then, that the terminal velocity of a free-falling PM-1 cask, at standard conditions, will lie in the approximate range between 1480 and 1600 ft/sec. This may be contrasted with the 43.9 ft/sec velocity to be obtained upon impact in a 30 foot drop test.

## BIBLIOGRAPHY

1. Glasstone, Samuel, Principles of Nuclear Reactor Engineering, D. Van Nostrand Company, Inc., New York, 1955.
2. Manual for Refueling the SM-1 Reactor, U. S. Army Engineers Reactor Group, Fort Belvoir, Va., May 1962.
3. Final Hazards Summary Report, ML-1 Nuclear Power Plant, Report No. IDO-28560, AEC R&D Report, Aerojet-General Corp., San Ramon, Calif., November 1960.
4. ML-1 Transport Manual, AGN TM-389, Aerojet-General Nucleonics, San Ramon, Calif., October 1961.
5. Sanger, E. L., ed., Medical Aspects of Radiation Accidents, U. S. Atomic Energy Commission, prepared under contract AT(30-1)-2106, 1963.
6. Radiological Health Handbook, PB 121784, U. S. Dept. of Health, Education, and Welfare, Public Health Service, January 1957.
7. Handbook of Federal Regulations Applying to Transportation of Radioactive Materials, U. S. A. E. C., May 1958.
8. Physical, Biological, Administrative Problems Associated with the Transportation of Radioactive Substances, National Academy of Sciences - National Research Council, publication 205, 1951.
9. Education and Orientation Program - Transportation of Radioactive Materials, U. S. A. E. C., Washington, D. C., Sept. 26, 1962.
10. Patterson, D. E., An Analysis of the AEC's Accident Experience in Shipping Radioactive Materials, U. S. A. E. C., Division of Operational Safety.
11. A Summary of Incidents Involving USAEC Shipments of Radioactive Material, 1957-1961, Patterson & DeFatta, U. S. A. E. C., T. I. D. - 16764, November 1962.
12. Guide to Nuclear Power Cost Evaluation (Vol. 4. Fuel Cycle Costs), TID-7025. (Vol. 4.), USAEC, prepared by Kaiser Engineers, Division of Henry J. Kaiser Co., Oakland, Calif., 15 March 1962.
13. Poindexter, A., Air Transportation of Radioactive Materials, RADC-TR-59-198, AMF Atomics, Greenwich, Conn., October 1959.
14. Shipping Container Testing Program: Report of Conference Held at Johns Hopkins University, May 2-3, 1962. U. S. A. E. C. TID-7635, August 1962

15. Messenger, W. de. L.M. and A. Fairbairn, The Transport of Radiactive Materials; Interim Proposals for the Application of Environmental Tests to the Approval of Packaging, United Kingdom Atomic Energy Authority, Authority Health and Safety Branch; AHSB(S) R. 19 (2nd Formal Draft), Sub. Ref. TCAP/P. 47, May 1962.
16. Spent Fuel Shipping Cask for PM-1, Martin Marietta Corp., Nuclear Division.
17. Messenger, W. de. L.M., The Transport of Radioactive Materials; The Application of Tests to the Approval of Packaging (Approved for very limited distribution by A. Fairbairn), United Kingdom Atomic Energy Authority; Authority Health and Safety Branch, TCAP/P. 45., Jan. 1962.
18. Blatz, Hanson, Radiation Hygiene Handbook, McGraw Hill Book Co., New York, 1959.
19. Regulations for the Safe Transport of Radioactive Materials, International Atomic Energy Agency, Vienna, (Safety Series No. 6), 1961.
20. (U) Preliminary SNAP 10A - SNAPSHOT Safety Report SSS-T62-1, NAA-SR-6684, LMSC - 44855A, Lockheed Missiles and Space Company & Atomics International, a division of North American Aviation, Inc. (S-RD report)
21. Newcombe, Sulit, and Heiman, Preliminary Evaluation of Radiological Hazards Associated with Operation of Nuclear-Powered Devices at Pacific Missile Range - Part 1, NRDL TR-497, 20 Feb 1961.
22. Federal Register, Radiation Protection Guidance for Federal Agencies, Federal Radiation Council, Pg 4402-3, 18 May 1960.
23. Permissible Dose from External Sources of Ionizing Radiation, National Bureau of Standards Handbook No. 59, with Addendum, 8 Jan 1951, Maximum Permissible Exposures to Man, and with Addendum, 15 Apr 1958, Maximum Permissible Exposures to Man.
24. Radiation Protection. Recommendations of the International Commission on Radiation Protection, Pergamon Press, Adopted 9 Sep 1958.
25. Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and Water for Occupational Exposure, National Bureau of Standards Handbook No. 69, 5 June 1959.
26. Principles of Radiation and Contamination Control, NAVSHIP 250-341-3, Bureau of Ships, 1960.
27. USAF Radiac Equipment, Directorate of Nuclear Safety, Office of the Deputy Inspector General for Safety, United States Air Force, Kirtland AFB, New Mexico, LSAG 62-1, 1962.
28. Binder, R. C., Fluid Mechanics, Prentice-Hall, Inc., New York, (2nd edition)

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A study was made to investigate the prime considerations involved in air transportation of nuclear reactor components, radioactive wastes, and radioisotope power-generating units. The logistics, economics, and safety of supplying a remote military nuclear power plant by air and of transporting SNAP-type reactor and radioisotope auxiliary power units by USAF aircraft are explored in detail. (U)

It was determined that such air transport operations are feasible and reasonably safe if proper planning is accomplished in the design of equipment and in the definition of mission profiles and ground handling procedures. Container criteria and procedural standards for the transport of the different categories of materiel are recommended. (U)

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