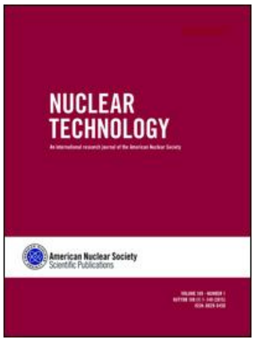

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TRANSPORTATION OF NUCLEAR FUEL AND WASTE

RADIOACTIVE WASTE

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With the sharp rise in nuclear shipments, public concern and outcry over the safety of these shipments has mounted. A million nuclear shipments are made nationwide each year. Government regulations require that shipments of large amounts of nuclear materials be made in accident-proof packages, carefully manufactured and inspected. "Torture-test" requirements are specified, along with the packaging methods for different types of nuclear materials. Calculations of the likely frequency of transport accidents, as well as the frequency of releases of nuclear materials in those accidents, lead to estimates of the overall public risk from nuclear shipments, along with some comparative guidelines on determining the acceptability of that risk.

INTRODUCTION

We live in a world of hazards. We are surrounded by threats to our health, our welfare, and our economy. Among the many hazards we face is one involving the transportation of hazardous material. The transportation of nuclear materials is on the increase. Although nuclear shipments are only a very small fraction of the nation's hazardous materials shipments, they attract a great deal of public attention. Shipments of spent nuclear fuel and nuclear wastes are of particular concern.

Public safety in the transportation of hazardous materials has been the subject of increasing emphasis. An article in the May 1970 issue of the *Reader's Digest* stated, "Transportation of hazardous materials on our roads, railroads, and waterways is a major and growing problem. One of every ten trucks rolling toward you on the highway today carries explosives, flammables, or poison."[1]

One of the many fears people have about nuclear energy is the possibility that a nuclear shipment might somehow go awry and cause a serious public hazard. Primarily, they are worried that a shipment of spent reactor fuel or highly radioactive waste could be involved in a serious rail or highway accident, and its contents be dumped all over the countryside.

Is that really possible? How safe are those shipments? How many are there? What do they look like? Are the packages tested? Questions have arisen in numerous public hearings on nuclear reactor operations with regard to the adequacy of public safety in the transportation of nuclear materials to and from nuclear reactors and fuel reprocessing plants. This paper presents a summary of the potential hazards of shipping those nuclear materials. During a span of almost 30 years of nuclear shipments, there hasn't been a single death or injury due to the radioactive nature of the shipments; nor has there been a release of nuclear materials serious enough to cause death from injury. Any risk analysis of nuclear shipment hazards must therefore be based only on the theoretical hazards. Since public risk is the product of the probability of an accident and its consequences, both aspects are presented so that each of us can make up his own mind whether the risk from nuclear shipments is acceptable.

WHAT IS SHIPPED?

Nuclear power will play an increasingly important role in meeting the nation's energy requirements. As nuclear power increases, the quantities of nuclear materials which must be shipped will also increase.

The operation of nuclear power reactors will usually require the transportation of three different types of materials to and from reactor facilities. Unirradiated ("cold" or "fresh") nuclear reactor fuel elements are transported from fuel fabricators to the reactor. Irradiated ("spent") fuel elements and nuclear wastes are shipped from reactor facilities to fuel reprocessing plants and to disposal sites. Also, the radioactive products of the spent-fuel reprocessing plants consist primarily of recycled nuclear fuel materials shipped to fuel fabricators or processors and both high- and low-level waste shipped to storage or disposal sites.

Other shipments of radioactive materials are made in support of nuclear power plant operations. For example, uranium concentrate, produced from uranium ore, is shipped from uranium milling plants to uranium conversion facilities for conversion of the uranium concentrate to uranium hexafluoride. Uranium hexafluoride is shipped to one of the U.S. Atomic Energy Commission (USAEC) uranium-enrichment facilities. The enriched uranium hexafluoride is then shipped to other plants which convert the material to uranium oxide which is then fabricated into fresh reactor fuel elements.

The Department of Transportation (DOT) has estimated[2] that there are nearly one million shipments of nuclear materials each year. About 95% of the shipments involve small quantities of nuclear isotopes for use in industry, medicine, agriculture, and education. By comparison, the total number of shipments of nuclear materials to and from nuclear power plants in 1971 probably numbered only a few thousand.[3] By the year 2000, however, the number of shipments to and from nuclear power plants will probably increase by at least 100 and perhaps as much as 1000 (Ref. 4).

Shipments of nuclear materials are not readily distinguishable from shipments of other hazardous materials transported in routine commerce. They look like ordinary shipments. They are usually handled and loaded in an ordinary manner, using ordinary freight handling equipment. They are transported on a worldwide basis, like other shipments, in the cargo compartment of an airplane, in a closed trailer or railroad boxcar, on "low boys" over highways, or on heavy-duty railroad flatcars.

They are not readily distinguishable, but there is a difference. Nuclear materials, like many other materials, have hazardous properties. These properties must be considered in the transportation of nuclear materials—considered from the viewpoints of possible radiation exposure to people, contamination of property, and overall effect on the environment. As a result of extensive research studies on the hazards and experience in handling nuclear materials, their properties are better understood than the properties of most other hazardous materials transported in far greater volume.

PRINCIPLES OF NUCLEAR SHIPMENT SAFETY

Packaging requirements for nuclear materials are designed to provide a high degree of protection and safety for the public and for the materials shipped under normal conditions of transportation and in severe accidents.

Protection of the public and transportation workers from radiation during shipments of nuclear fuel and waste is achieved by limitations on both the contents (according to quantities and types of radioactivity) and the package design. Because nuclear shipments move in routine commerce and on conventional transportation equipment, they are subject to normal transportation accident environments[5] like other non-nuclear cargo. The shipper has essentially no control over the likelihood of an accident involving his shipment. The result is that there have been and will continue to be accidents involving nuclear materials. The shipper can maintain control over the consequences of accidents by controlling the package design, contents, and external radiation levels. Safety in transportation does not depend only upon special handling or special routing.

In the transportation of all types of hazardous materials, there is a difference between potential hazards and realized damage. For hazardous materials, a system of protection is used to reduce the potential hazard from becoming a reality. A highly developed and sophisticated system of protection has evolved for the transportation of nuclear materials. This system is based upon a simple principle: If a package contains enough radioactivity ("Type B" quantity) to present a significant risk of injury or large property loss if released, then the package ("Type B" package) must be designed to retain its contents during severe transportation accidents.[6] Lesser quantities of radioactive materials ("Type A" quantities) do not require as much protection, but still must be packaged in high quality "Type A" packaging, designed to withstand less severe transportation accidents. In addition, all packages (Types A and B) are required to completely retain their contents during normal conditions of transportation.[7] In other words, accidents that involve nuclear materials should not release any serious amounts of nuclear materials.

The basic principles of safety are translated into the Federal Government regulations.

GOVERNMENT REGULATIONS

The transportation of nuclear materials is subject to regulation by both the DOT (Ref. 8) and the USAEC (Ref. 9). The DOT Hazardous Materials Regulations also provide for safety in shipment of other more routinely shipped hazardous materials—materials which are flammable, unstable, poisonous, explosive, or corrosive. The same basic safety standards governing shipments of nuclear materials in the U.S. are in worldwide use through the regulations of the International Atomic Energy Agency (IAEA).[10]

Packaging must provide adequate radiation shielding to limit radiation exposure to transportation workers and the general public. For spent-fuel and high-level nuclear wastes, the package must have heat dissipation characteristics to protect against overheating from the self-heating character ("radioactive decay heat") of those materials. For both fresh and spent fuel, package design must also provide nuclear criticality safety under both normal transportation and severe accident conditions.

Package designs are reviewed by the USAEC prior to use to verify the adequacy of design parameters. If it appears that the package will, in fact, meet regulatory requirements, the USAEC issues a certificate of approval for the package.

SHIPMENT INFORMATION

Department of Transportation regulations specify the type of information which must appear on bills of lading and other shipping papers. Packages are required to be labeled appropriately. Warning placards generally must be placed on the transporting vehicle. This puts the carrier and emergency personnel on notice that they are handling shipments of hazardous goods. It alerts them to the fact that applicable state and local regulations and ordinances must be followed.

QUALITY ASSURANCE

It is possible that the adequacy of the package design could be compromised or circumvented by errors which occur during fabrication, maintenance, or handling of the package. The person loading and closing the package could make errors. Perhaps one or more bolts could be left out or not properly tightened; a gasket could be misplaced or omitted; a brace or "holddown" piece could be left off. The chances of such errors are limited because of the procedures required by the regulations for examination of the package prior to each shipment, including tests for leak tightness, where necessary. Redundancy of safety features on the package reduces the consequences of such operational errors, should they occur.

Use of the wrong materials or errors in fabrication also could result in the packaging failing to function properly during transportation. Good quality assurance programs increase the likelihood that such errors would be detected and corrected prior to use. The regulations[9] impose certain quality assurance requirements on both shippers and package manufacturers. The shipper is required to determine that each package meets approved design specifications. All these things limit both the likelihood and the results of a release during both normal and accident conditions.

TYPES OF RADIOACTIVE WASTES

Different types of radiation have different penetrating abilities, and different biological damage potential. For example, alpha particles have a very short range in air and cannot even penetrate a piece of paper; beta particles travel a longer distance, but still can be shielded completely by light low-density materials such as aluminum; gamma rays require thicker or more dense shielding materials such as lead and steel. The chief hazard to human beings from alpha materials would be from deposition of the materials within the body, so special care must be taken in containment of alpha-particle wastes. Beta-gamma wastes also require maintenance of container shielding.

There are several different types of nuclear wastes. Nuclear wastes which are shipped around the country to various processing, storage, or burial sites fall into four general categories: (a) low-level wastes, (b) high-level wastes, (c) alpha wastes, and (d) other wastes.

Low-level wastes contain such low concentrations or quantities of radioactivity that they do not present any significant environmental hazards. Even if released from their packages in a transportation accident, they would not present much hazard to the public. Like any other freight spilled at the scene of an accident, low-level wastes would have to be cleaned up because of their nuisance value. Under U.S. and international regulations, they require only normal industrial packaging for shipment and require no special rail cars or other transport vehicles. Low-level wastes may include such things as residues or solutions from chemical processing; building rubble, metal, wood, and fabric scrap; glassware, paper, and plastic; solid or liquid plant waste, sludges, and acids; and slightly contaminated equipment.

High-level wastes are solidified wastes from the reprocessing of highly irradiated nuclear reactor fuels. These wastes have such a high radioactive content of long-lived isotopes that they require long-term storage in isolation and essentially perpetual surveillance of the storage sites. The radiation level is high enough to produce considerable heat, and the material must be heavily shielded. The waste is inert, immobile, solid material which is nonexplosive, noncombustible, and cannot turn to gaseous form and become airborne. The most common type of high-level waste shipments is the solidified (process) waste from nuclear fuel reprocessing plants. Only solid materials of this type will be shipped to waste storage sites, since the sites, to be operated by the USAEC, will not be equipped to handle and store liquids.

Alpha wastes usually consist of materials which are contaminated with alpha radiation emitters such as plutonium. They have very low levels of penetrating gamma radiation and so do not require heavy shielding. Alpha emitters have the potential for causing contamination of objects or people if released from their packages.

Other wastes are predominantly of the beta-gamma type (e.g., fission product, industrial isotopes) which usually requires some shielding material as a part of the package. This waste may also be a combination of LSA, alpha, and beta-gamma types. Beta-gamma waste includes such things as irradiated reactor structural components, heavily contaminated objects, concentrated solidified sludges or evaporator bottoms, and nonrecoverable radioactive fuel scrap.

PACKAGE INTEGRITY

Before a specific design of Type B package is approved by the USAEC for shipment of nuclear materials, it must be capable of withstanding, without leakage, a series of "torture tests" which produce damage conditions comparable to the actual damage a package might incur in a hypothetical severe transportation accident. The accident damage test sequence specified in DOT and USAEC regulations includes a high-speed impact test, followed by a puncture test, followed by a fire test. A water immersion test is also required.

This test sequence represents the type of damage which might occur to a package in a high-speed truck accident or train derailment, causing the package to impact on a hard surface (such as a bridge abutment) and then to smash through wreckage or onto rocks, and then to be directly involved in a 2- to 4-h cargo fire, and then to roll down into a river! The regulations therefore offer a very high degree of assurance that a package will not breach under severe accident conditions. It might leak a little, but it won't break apart.

A specific safety analysis report must be prepared for each package type and evaluated by the USAEC before use. Only if the packaging has successfully passed such rigorous evaluation does the DOT authorize its use. At present, there are several hundred different types of radioactive material package designs that have been authorized, ranging in size from small packages weighing a few pounds to massive casks weighing over 100 tons.

PACKAGING METHODS

Fresh Fuel

A "typical" package for a "typical"[10,11] light-water reactor fuel is a cradle assembly consisting of a rigid beam or "strongback" and a clamping assembly which holds a few fuel elements firmly to the strongback. The strongback is shock-mounted to a steel outer shell. Fresh fuel elements might also be shipped in steel boxes positioned in an outer wooden box by a cushioning material. These packages, also with a few fuel elements inside, would be about 2 to 3 ft in diameter or cross section, and about 17 ft long. They would weigh from 1000 to 9000 lbs. Typical containers are shown in Figs. 1 and 2.

Spent Fuel

Because irradiated fuel elements are highly radioactive, their containers must be very heavily shielded. A typical "cask" used for shipping spent fuel would weigh between 20 and 175 tons. It would be constructed of thick steel walls filled with a dense shielding material such as lead, tungsten, or depleted uranium. Each cask would carry 1 to 7 PWR elements, or 2 to 18 BWR elements. The casks would be generally cylindrical in shape, and perhaps 5 ft in diameter and 15 to 18 ft long. A recently designed cask of this type is shown in Figs. 3 and 4.

The cask must not only provide radiation shielding, but must also provide the means to dissipate the large amount of heat (perhaps 75 000 Btu/h) produced by radioactive decay. Water is usually used in the central cavity as a heat transfer medium or primary coolant to transfer the

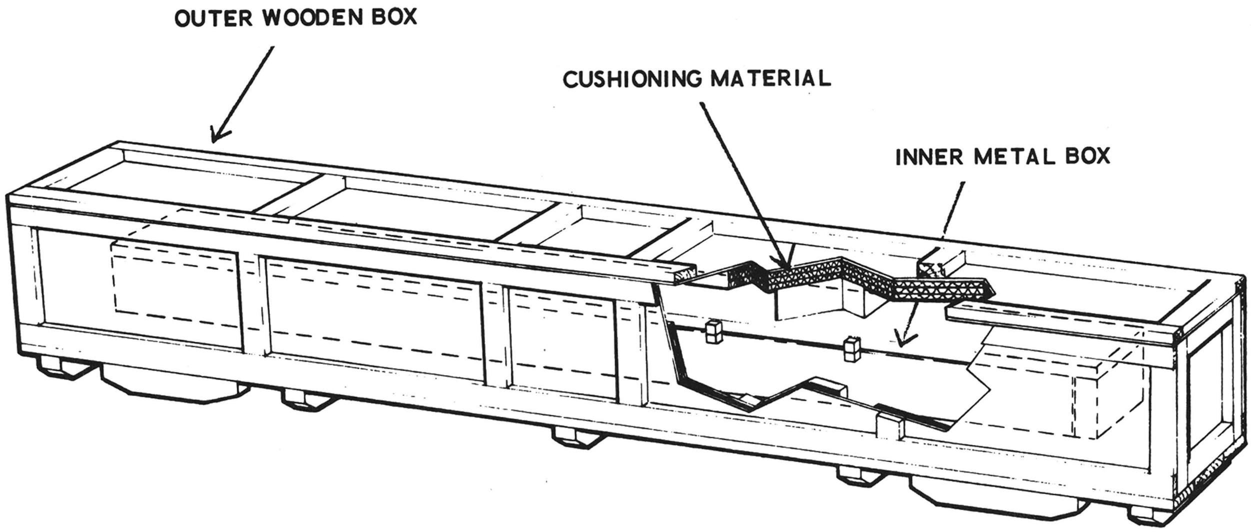

Fig. 1. BWR fuel element shipping container.

decay heat from the fuel elements to the body of the cask. The heat is usually dissipated to the air by natural processes through fins on the surface of the cask. For some of the larger casks, air may be forced over the fins by blowers to increase the cooling. In other casks, heat exchanges with cooling coils running into the body of the cask literally pump the heat out and into the atmosphere. Reliable, redundant systems are used where such mechanical systems are needed to ensure adequate cooling.[12]

High-Level Nuclear Waste

Shipping containers for high-level waste shipments are very similar in their basic design to the shielded casks routinely used to ship spent-fuel assemblies from a nuclear power plant to a fuel reprocessing site. Canisters of high-level waste will be very similar in overall shipping characteristics to spent-fuel elements in that they are highly radioactive and generate considerable heat. In both cases, the shipping casks would be essentially the same type—large steel casks, lined with lead, steel, or uranium. The high-level waste actually will be in a capsule or canister within the outer shielded cask. These high-level waste casks would be transported by rail on conventional heavy-duty flatcars. Highway load limits, rather than safety reasons, may restrict highway shipments.

No detailed cask designs have yet been submitted by industry for USAEC approval, since shipments to a storage facility will probably not begin until the early 1980's (Ref. 13).

Alpha Waste

If the amount of nuclear material exceeds certain levels of concentration, the alpha wastes must be packaged in Type B packages, but of a different type than the very heavy high-level waste packages. The emphasis in packaging for transportation is on containment, with several containment barriers provided in the packaging system. Alpha waste is shipped either in a large accident-proof box or in a bundle of 55-gal drums encased in an outer protective container for protection from impact and fire. Special railroad cars already constructed have been used to transport USAEC-produced solid alpha wastes to a storage facility. Other methods and modes of transportation may be used in the future.

Low-Level Nuclear Waste

Under DOT regulations,[8] low-level solid waste is packaged depending on the amount of radioactivity in the package. Typically, the waste is solidified in a mixture of vermiculite and cement in Type A steel drums. When filled, the individual drums weigh between 500 and 800 lbs. If the drums contain Type B quantities of waste, the drums would require the addition of a Type B "overpack" (i.e., protective outer packaging) to provide accident protection for the drums. Low specific-activity wastes or Type A quantities of waste may be shipped in drums without protective overpacks.

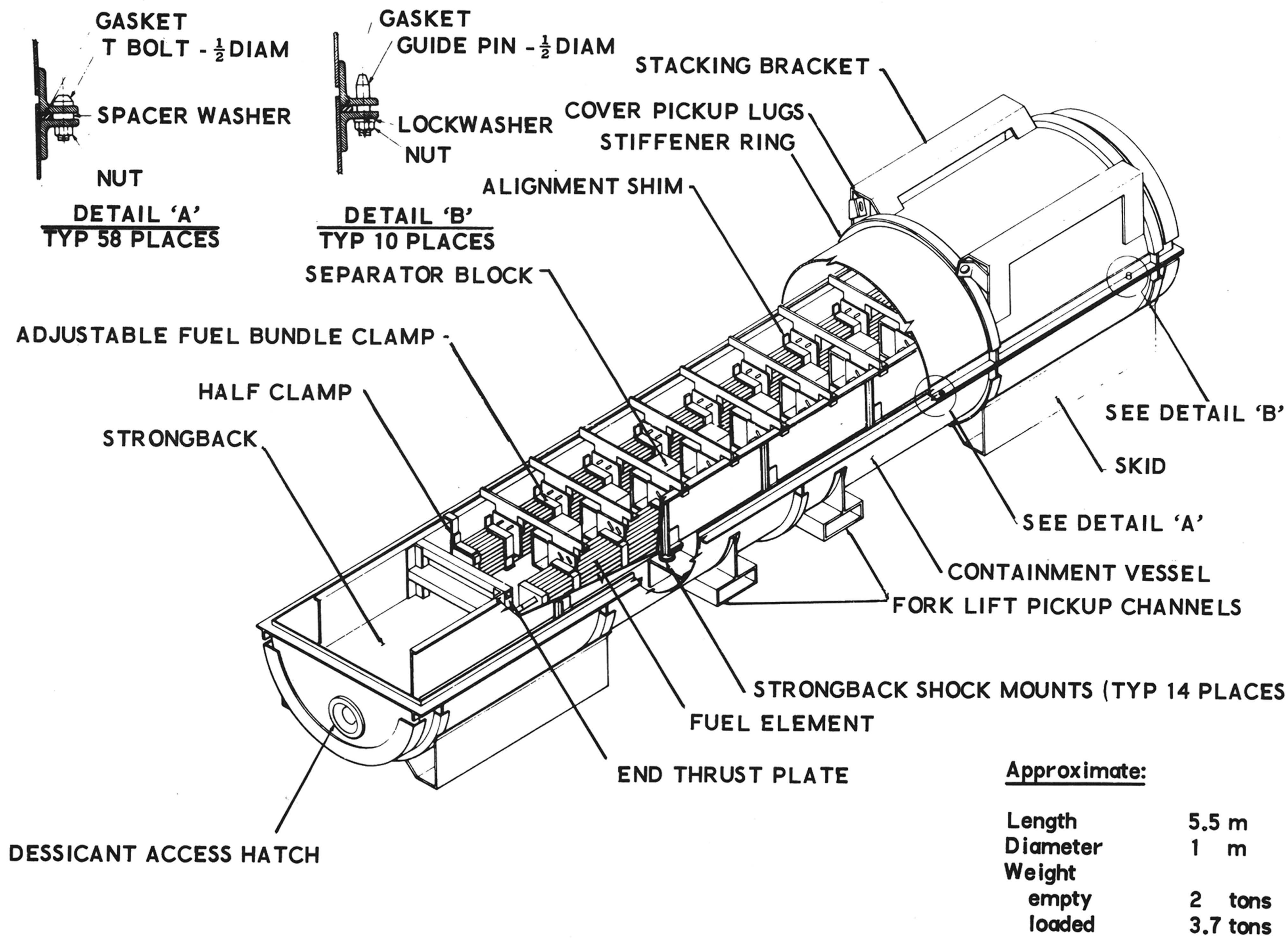

Fig. 2. PWR fuel element shipping container.

NUMBER OF SHIPMENTS

Pattern of Shipments

Shipments would be nationwide, predominantly in the east. Reactor locations as of Jan. 1, 1974 are shown in Fig. 5. Fuel reprocessing plants are located in New York, Illinois, and South Carolina. Fuel fabricators are scattered throughout the east. There are commercial waste burial sites in New York, South Carolina, Illinois, Nevada, Washington, and Kentucky.

Fresh Fuel

Each year, on the average, about one-third to one-fifth of the fuel in a reactor is replaced with fresh fuel. Fresh fuel is usually shipped by truck, with 6 to 16 packages per truck. About six truckloads of fresh fuel elements would be shipped to a reactor each year. For 200 reactors, that's 1200 truckloads per year nationwide.

Spent Fuel

At present, all shipments of spent fuel are made under "exclusive use" arrangement, by truck or rail. Some barge shipments may be made in the future. There would be about 10 rail shipments or 40 truck shipments annually from each reactor to a fuel reprocessing plant. For 200 reactors, that's 2000 rail shipments or 8000 truck shipments per year.

High-Level Waste

At the present time, the USAEC is planning on long-term storage of all high-level wastes from commercial fuel reprocessing plants at a federal waste repository or engineered storage facility. Some intermediate level fission product wastes may be further treated for separation into high-level and low-level components, the former of which would be destined for shipment to a federal storage facility, and the latter for shipment to commercial burial facilities.

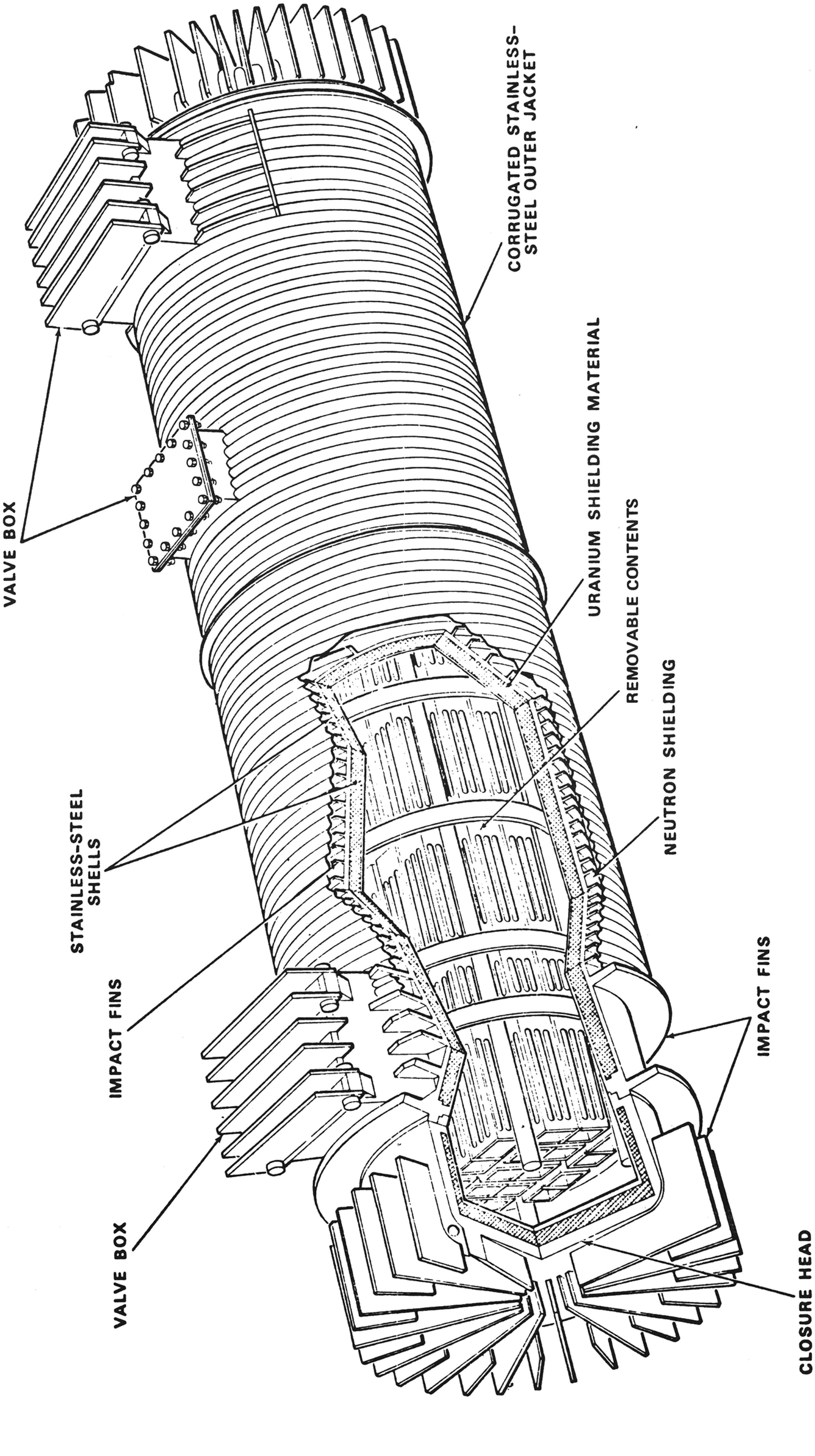

Fig. 3. Shipping cask.

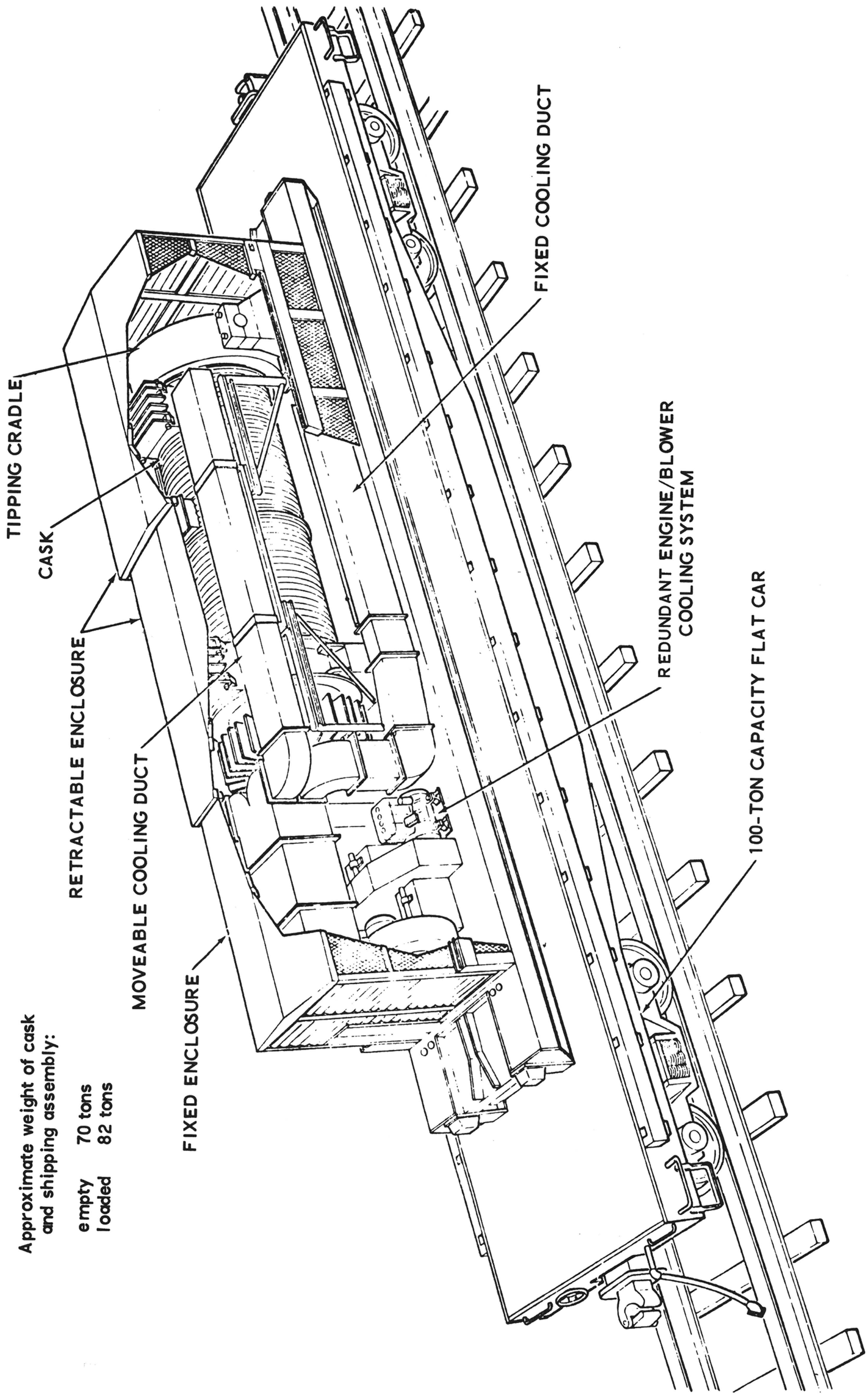

Fig. 4. Irradiated fuel cask on rail car.

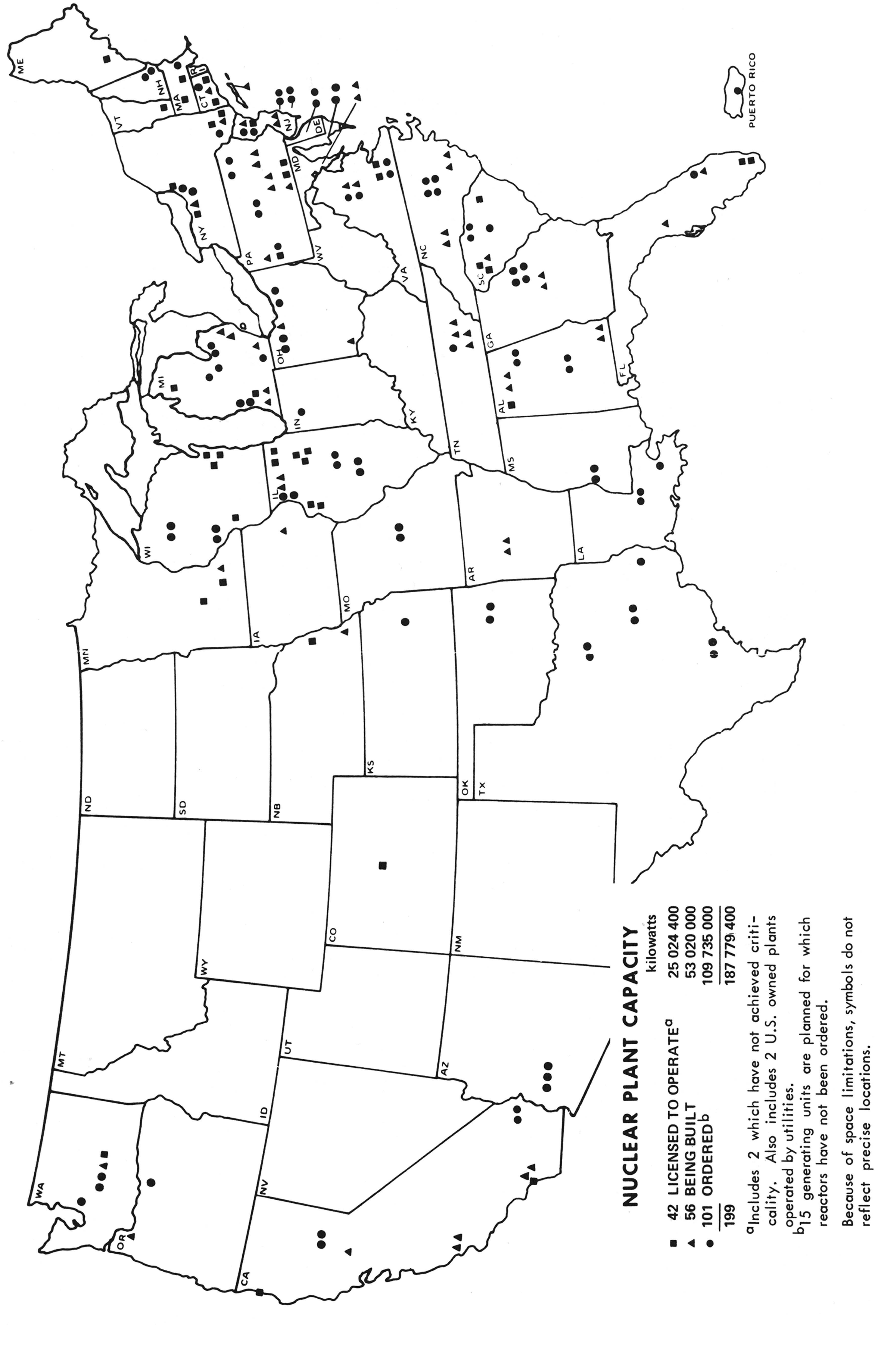

Fig. 5. Nuclear power reactors in the United States.

The first shipments of high-level waste from reprocessing plants are not expected until about 1983. By 1985, there will be about 25 shipments a year. By 2000, there may be about 260 shipments per year, for four reprocessing plants.[13]

Alpha Waste

Each reprocessing plant is expected to produce about 5000 ft^3 of alpha waste per year. This would be about 30 rail carloads or 150 truckloads each year for three presently planned reprocessing plants.

Low-Level Waste

About 4000 ft^3 of low-level waste per year would be shipped from a BWR, and about 1000 ft^3/yr from a PWR. Most of the shipments would be made by truck. About 2000 drums of radioactive waste would be shipped, with about 40 to 50 drums per truckload, for about 45 truckloads per year for a BWR. For a PWR, there would be about 500 drums and 10 truckloads per year. Each reprocessing plant is expected to produce about 20 000 ft^3 of low-level waste per year. There would be about 700 truckloads each year for three reprocessing plants.

ACCIDENTS

Accidents occur in a range of frequency and severity. Most accidents of the cargo is not a factor, accidents often result in injury, death and cargo or other property loss due to common causes.

Truck Accidents

In 1972, motor carriers reported[14] a total of about 64 500 accidents, 29 000 injuries and 2100 deaths, along with $132 million in property damage. The injury rate is about 0.65 injuries per accident and the death rate is about 0.03 deaths per accident. The accident rate for shipments is about 1.7 accidents per million truck miles and about 0.53 accidents per million truck miles for hazardous materials shipments.

Rail Accidents

In 1972, the rail industry reported[15] about 7500 accidents, 18 000 injuries and 1950 fatalities. The accident rate for rail accidents was about 1.5 accidents per million car miles. There were about 2.4 injuries per accident and about 0.26 deaths per accident.

Nuclear Materials

To date, there have been no injuries or deaths of radiological nature due to the transportation of nuclear materials.[2] There have been a few cases of truck drivers being killed or injured as a result of a collision or overturn of vehicles carrying nuclear materials. In none of these cases, however, was there any release of nuclear materials from Type B packages.

In recent years, DOT has recorded an average of 8000 to 9000 incidents per year involving the transportation of hazardous materials, of which 15 to 20 involve nuclear materials. Almost all these incidents involved Type A (exempt) packages. In about two-thirds of these cases, there was no nuclear material released from the packages. In a few percent of the cases, there was significant contamination requiring cleanup, with cleanup costs running into the thousands of dollars.

ACCIDENT RISK

Principle of Risk

The significance of radiological hazards during transportation of nuclear materials can be properly evaluated only by considering both the consequences of accidents and the probabilities of those accidents. One could compare the risks of transportation of nuclear materials in several ways. For example, one might compare the probabilities of shipment accidents[15,16]; one might compare the average cost of accidents by each mode of transportation; one might compare direct transportation costs, which include insurance premiums. However, all these partial measures for comparing risk may be combined into a single contingency risk cost factor which is the product of the probability of experiencing an accident involving nuclear materials and the probable cost of such an accident if it occurs. In late 1972, the USAEC completed a study[11] of this type of comparison for nuclear reactor power plant transportation.

Magnitude of the Risk

In estimating the radiation risk from accidents involving nuclear shipments, one must consider (a) the frequency and the severity of accidents, (b) the likelihood of package damage or failure, (c) the nature, amount, and consequences of releases of radioactivity during an accident, and (d) the capacity of coping with such releases.

The overall environmental effects which might occur in transporting nuclear fuel and solid wastes resulting from the operation of a "typical" power reactor have been evaluated.[1] That risk analysis covers transportation of (a) fresh fuel from a fabricated plant to a reactor by truck, (b) spent fuel from a reactor to a fuel reprocessing plant by truck, rail, or barge, and (c) solid wastes from a reactor to a radioactive burial site by truck or rail. The range of known distances between various sites was considered. Estimates were made of radiation effects on the environment under normal conditions of transportation and for credible severe accidents. The potential accidents were analyzed in terms of severity and predicted damage, and the probable consequences of releases. Finally, by combining the probabilities of accidents with the consequences, the overall risk of transportation accidents was estimated.

Normal Conditions

According to the USAEC analysis,[11] truck drivers and freight handlers would normally receive an average of about 0.2 to 0.3 mrem per shipment of fresh fuel. No member of the general public is likely to receive more than about 0.005 mrem per shipment. Most exposure to the general public would be nonrepetitive in that no single member of the general public would be exposed to those dose levels more than a few times per year. The most that any one member of the general public might receive during a year might then be perhaps 0.01 mrem or about 1/50 000 of his annual permissible man-made exposure. By comparison, the average annual exposure from other sources (such as the natural radioactivity of the earth, medical exposures, and cosmic radiation) is about 150 mrem, or 15 000 times greater than from nuclear shipments.

For spent fuel and radioactive waste shipments, each truck driver could receive as much as 30 mrem per shipment. A few members of the general public could receive as much as 1 mrem per shipment, or about 1/500 of his annual permissible exposure.

Frequency and Severity of Accidents

Based on the DOT accident statistics, one can calculate how many accidents involving nuclear shipments might be expected each year. For example, assuming 100 000 truck-miles per year of transportation for each nuclear power plant, and with 200 such plants, one can expect about 13 accidents per year involving nuclear reactor shipments. Those accidents would produce nine injuries per year, and one death every two years, from conventional or common causes not related to the nuclear nature of the cargo. There was one such death in 1973, when a truck carrying a spent-fuel cask overturned, killing the driver. The cask was undamaged.

For rail accidents, there were about three injuries per accident on the average, and about 0.3 deaths per accident. Assuming 15 000 railcar miles per year per reactor, and with 200 reactors, there might be two accidents with five injuries and a death every other year, involving nuclear shipments. Again, these deaths and injuries would not be related to the nuclear nature of the shipments.

The USAEC environmental study[11] showed that only a very small fraction of the total accidents would be severe—about 1 out of 70. We can expect perhaps 15 accidents per year, but there will be only one severe accident every five years.

Likelihood of Package Damage or Failure in Accidents

As already pointed out, the vast majority of accidents involving nuclear shipments will result in no release of nuclear materials, or injury or death due to radiation. What does "vast majority" mean? According to another USAEC study,[17] only about one transportation accident in every two million could be violent enough to cause a large enough cask breach to present a serious public hazard. Leakages from smaller packages, such as those containing radiopharmaceuticals, will be hundreds of thousands of times more common, and have already occurred at the rate of several per year, about one for every 100 000 packages shipped. That rate is likely to continue. However, for the "accident-proof" Type B casks, accidents which are even more severe will cause no cask failure. A few percent of severe accidents would probably cause some minor leaks, but no major ruptures. Only in the worst conceivable accidents are there likely to be any releases of nuclear materials that could potentially cause injuries, deaths, or expensive cleanup due to radiological causes. How many deaths or injuries? How much property loss?

Consequences of Package Failure

Obviously, if there is no failure of the package, and damage is only superficial, the hazard is the same as any other heavy object flying around in a wreck.

In the case of minor cask leakage, there could be no nuclear deaths, and probably no injuries, either. Radiation levels would be too low. Low levels of radioactive contamination would be present over an area of about one-tenth square mile,[18] costing upward of $50 000 to clean up.

How about the case of the "impossible" accident—one so violent that the cask shell would rupture? First of all, the damage effects of a gross leakage, should it occur, would be local, not widespread. If it were possible for a high-level nuclear waste canister to be removed from its cask enroute and left exposed, it could cause death (400-rem exposure assumed) to people within 100 ft, but only if they were to remain there for an hour or more. Shorter exposures would kill fewer people; longer exposures would kill more. Serious injuries (150-rem exposure assumed) could result from 1-h exposures out to perhaps 150 ft. Beyond 350 ft there would be no radiation injuries at all, and certainly no deaths. Common fears of thousands of deaths are unfounded, because it is so highly unlikely that there would be so many people within 100 ft of the blazing inferno required to cause a major breach of the cask. Even if they were there at first, having come running at the sound and sight of a wreck, the fire would drive them away beyond the hazardous area. Accidents so serious would involve a lot of wreckage, and access would be restricted within a short period of time. The number of deaths and injuries from the resultant conventional crash effects of such a violent wreck would probably be much greater than those likely from the nuclear effects of an exposed load.

Even in a serious wreck, with as much leakage from the cask as is credible under those conditions, the contamination would not be widespread. There could be high levels of contamination, comparable to the radiation levels described above, within 100 ft or so, and for another 100 ft downwind, but the radiation levels would quickly taper off within about 350 ft to non-lethal levels. The cleanup of that area would present large but manageable problems, and costs could run as high as a few million dollars by some estimates. By comparison, serious rail accidents often result in property damage of many millions of dollars and also require massive cleanup, particularly when tank cars of poisonous or corrosive liquids have ruptured. The nuclear problems would be in the same order of magnitude physically and financially, but would, of course, present a more severe public relations problem due to the inevitable emotional reaction to serious nuclear accidents.

CONCLUSIONS

On the basis of the studies referred to, it appears that the probability of death, injury, or massive property loss due to transportation of radioactive materials is (a) determinable, (b) not zero, and (c) very small. In projecting the total accident probability for transportation of radioactive materials to and from nuclear power reactors and fuel reprocessing plants, it seems obvious that the overall radiological consequences of the total accident spectrum will be several orders of magnitude below the more common nonradiological causes. It further appears that radiation doses to transportation workers and the general public during the normal course of transportation will be limited to a small fraction of the total permissible annual dose, and then only to an extremely small segment of the population. The various studies show clearly that the likelihood of a catastrophic nuclear transport accident is so infinitesimal that, for all practical purposes, it can be confidently said that one will never happen.

The risk is small, but is it acceptable? And to whom? Modern life confronts people with a multitude of risks. We don't live in a riskless society, nor could modern technological societies exist on that basis. Each person has his own idea of what risks are acceptable to him. The public apparently judges the convenience of air travel to be worth the risk that results in 200 fatalities per year; the convenience of driving an automobile is considered worth much higher levels of risk. Some people are afraid of airplanes, but ride motorcycles. Sometimes the public judgments are not especially rational. About 49 million Americans continue to smoke cigarettes despite the clear warning of risk to their health printed on each package. Others smoke heavily, but take a vitamin pill every day to stay healthy. Many people are afraid of the potential hazards of nuclear power, but risk their necks every day in the hazardous reality of highway travel. Some say that risks which they choose to accept are acceptable, but risks imposed on them are not. In each case, the acceptability is most likely to be based on subjective emotional reactions—"gut" feelings rather than a logical analysis of accident data or other actual experience. Few of us are afraid of being bitten by a venomous snake or being attacked by a rhinocerous in the middle of Washington, D.C., but that probability is also (a) determinable, (b) not zero, and (c) very small.

Certainly laws and regulations themselves will not guarantee risk-free transportation. We are all aware of the potential risks in nuclear matters if safety is not given the very close attention it deserves. Transportation accidents and their potential effects on shipping containers have been well studied. These studies continue. It is precisely because of this perceived risk that the USAEC has always imposed stringent and overlapping protective measures in their concept of "defense in depth." However, one cannot claim "assurance" as an absolute. No safety system can nor should it be expected to guarantee complete safety of a few individuals who by very exceptional circumstances, peculiar habits, unusual customs, or extreme deviations from the typical individual get into difficulties. Even the normal industrial safety limits for a variety of hazardous stresses provide only reasonable protection for typical workers, and no more than that.

We tend to react to the problem of risk by making choices based on the magnitude of the risk, as we perceive it, and the benefits to be gained from accepting the risk.

The National Academy of Sciences has stated, "Whether we regard a risk as acceptable or not depends on how avoidable it is, and how it compares with the risks of alternative options and those normally accepted by industry." As a result of studies made, it is the USAEC's opinion[11,13] that, with regard to nuclear shipments

1. We have enough facts and figures on hazards to allow a more objective evaluation of the risk acceptability than we might derive solely from "gut" feelings.

2. The risk of public catastrophe has been eliminated by strict standards, engineering design safety, and operational care. Whatever the consequences of an accident, the public hazard will be manageable, and the nuclear effects will be small compared to the non-nuclear effects.

3. The long-term public burden of not transporting nuclear materials is likely to be higher than the risks of carefully controlled transportation, considering the various options available.

4. The likelihood of death, injury, or serious property damage from the nuclear aspects of nuclear transportation is thousands of times less than the likelihood of death, injury, or serious property damage from more common hazards, such as automobile accidents, boating accidents, accidental poisoning, gunshot wounds, fires, or even falls—all things which we can control, but which apparently have been accepted as a part of life without much public support for reduction of risk.

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