26 Apr 1974

Are Nuclear Shipments Really Safe?

William A. Brobst

ARE NUCLEAR SHIPMENTS REALLY SAFE?

Presented by:

William A. Brobst
Chief, Transportation Branch
Division of Waste Management and Transportation
U.S. Atomic Energy Commission
Washington, D.C. 20545

Before the:

First Annual UMR-MEC Energy Conference
University of Missouri
Rolla, Missouri 65401

April 24, 1974

ABSTRACT

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 a particular concern.

One of the many fears that 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 dump its contents 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? These and other questions are answered in this paper. Since public risk is the product of the consequences of an accident and its probability, both aspects are presented so that each of us can make up his own mind whether the risk from nuclear shipments is acceptable.

Introduction

We live in a world of hazards. We are surrounded by threats to our health, our welfare, and our economy. Amongst the many hazards we face is the one involving the transportation of hazardous materials. One of the hazardous materials with which we must concern ourselves is nuclear material.

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]

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 summarized status report on the potential hazards of shipping those nuclear materials. Since there have been no serious releases of nuclear materials in transportation accidents during the 25-year life of the Atomic Energy Commission, the paper is based on a theoretical analysis of accident risks.

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-level and low-level waste shipped to 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 in the western United States to uranium conversion facilities for conversion of the uranium concentrate to uranium hexafluoride. Uranium hexafluoride is shipped to one of the Atomic Energy Commission (AEC) 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 1,000,000 packages of nuclear materials shipped each year. About 95 percent 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 numbers of shipments to and from nuclear power plants will probably increase by at least 100 and perhaps as much as 1,000. [4]

Shipments of nuclear materials are not readily distinguishable from shipments of other hazardous materials being 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 highway, or on heavy duty flatcards by rail.

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 the depth of research studies of the hazards and experience in the handling of nuclear materials, their properties are better understood than the hazardous properties of most other hazardous materials being transported in far greater volume.

The packaging requirements for nuclear materials are designed to provide a high degree of protection and safety for personnel and materials, during both normal conditions of transportation and severe accidents.

Principles Of Nuclear Shipment Safety

Protection of the public and the transportation workers from radiation during the shipments of nuclear fuel and waste is achieved by a combination of limitations on both the contents (according to the quantities and types of radioactivity) and the package design. Because shipments move in routine commerce, and on conventional transportation equipment, they are, therefore, subject to normal transportation accident environments [5] just like other nuclear cargo. The shipper has essentially no control over the likelihood of an accident involving his shipment. He does have control over the consequences of accidents by controlling the package design, contents, and external radiation levels. Safety in transportation does not depend 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 likelihood of 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. [5,6] Lesser quantities ("Type A" quantities) do not require as much protection, but still must be packaged in high quality "Type A" packaging. In addition, all packages (Type A and B) are required to completely retain their contents during normal conditions of transportation.

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

Government Regulations

The transportation of nuclear materials is subject to the regulations of both the DOT [7] and the AEC. [8] 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 United States are in worldwide use through the regulations of the International Atomic Energy Agency. [9]

In addition, the packages must provide adequate radiation shielding to limit the radiation exposure to transportation workers and the general public. For spent fuel, the package must have heat dissipation characteristics to protect against overheating from radioactive decay heat. 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 AEC prior to use in order to verify the adequacy of the design parameters. If it appears that the package will, in fact, meet the regulatory requirements, [7,8] the AEC will issue a certificate of approval for the package.

Shipment Information

DOT 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 need to be followed.

Quality Assurance

The adequacy of the package design can be compromised or circumvented by errors which occur during fabrication, maintenance, or use 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 an error 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 will reduce the consequences of such operational errors, should they occur.

Use of the wrong materials or errors in fabrication also could result in a package failing to function properly during transportation. Adequate quality assurance programs increase the likelihood that such errors would be detected and corrected, prior to use. The regulations [8] impose certain quality assurance requirements on package manufacturers. The shipper is required to determine that each package meets the approved design specifications.

Types of Radioactive Waste

Different types of radiation have different penetrating abilities. For example, alpha particles have a very short range in air and cannot even penetrate a piece of paper; beta particles travel over a larger distance, but can still 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 the alpha wastes. Beta-gamma wastes also require maintenance of container shielding.

There are several different types of materials which may be found in nuclear wastes. Nuclear wastes which are shipped around the country to various processing, storage, or burial sites fall into three general categories: (1) low specific activity (LSA) wastes; (2) high-level wastes; and (3) other wastes.

Low specific activity wastes are those which contain such low concentrations or quantities of radioactivity that they do not present any significant environmental hazards. Even if they were 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, they 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. LSA 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 or objects.

Alpha wastes, high-level wastes, and other wastes contain sufficiently large amounts of radioactivity that they have a significant potential for injury or property damage if released to the environment during a transportation accident. For that reason, DOT and AEC regulations require that they be packaged such that, even in the event of a severe transportation accident, there would be no significant release of radioactive materials outside of the containers. The packages (Type B packages) must then be strong enough to withstand the types of impact and puncture forces and fire effects which are often encountered in severe accidents.

High-level wastes are those 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 most common type of high-level waste shipments will be the solidified (process) waste from the nuclear fuel reprocessing plants. Only solid materials of this type will be shipped to waste storage sites. Shipments of high-level liquid wastes are not presently allowed by the DOT, and are not practical due to problems in designing safe containers for bulk shipment of such liquids.

Alpha wastes usually consist of materials which are contaminated with alpha radiation emitters such as plutonium or other transuranium nuclides. 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. 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 containment, with several containment barriers provided in the packaging system.

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. Because of the presence of considerable quantities of nuclear material, packages of these materials must also be capable of resisting severe accident.

Package Integrity

Before a specific type of Type A package is approved by the AEC for shipment of nuclear materials, it must be capable of withstanding, without leakage, a series of "torture test" which produce damage conditions comparable to the actual damage a package might encounter in a hypothetical severe transportation accident. The accident damage test sequence specified in the DOT and AEC regulations includes a 30-foot fall onto a solid unyielding surface, followed by a 40-inch drop onto a 6-inch diameter piston, followed by exposure for 30 minutes to a 1475°F fire. 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 2-4 hour 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.

A specific safety analysis report must be prepared for each package type and evaluated by the AEC before use. Only if the packaging has successfully passed such rigorous evaluations 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" [16] 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 which are 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 feet in diameter or cross section, and about 17 feet long. They would weigh from 1,000 to 9,000 pounds. Typical containers are shown in Figures 1 and 2.

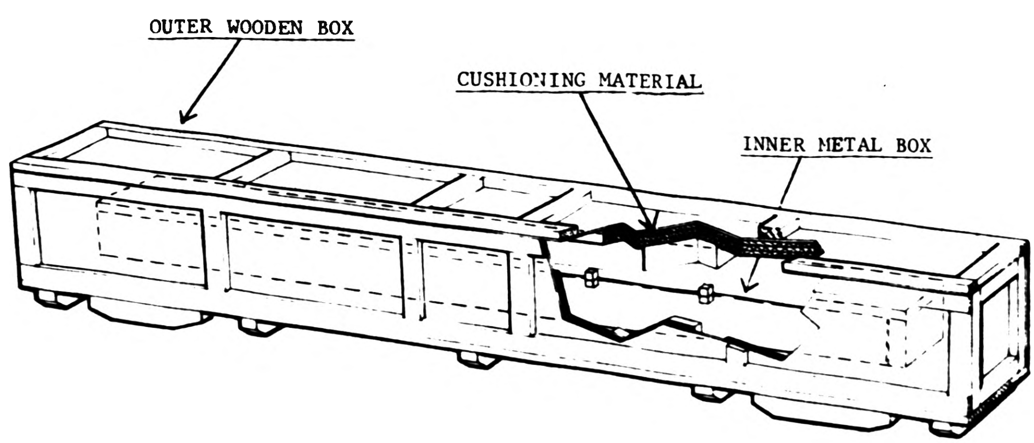
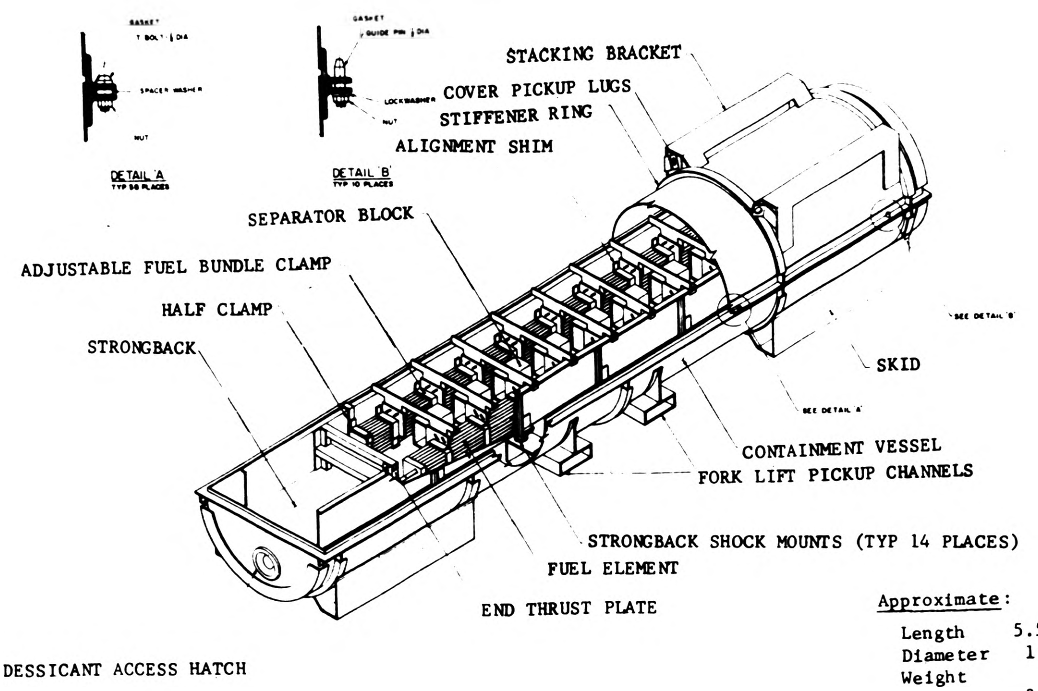


FIGURE 1
BWR FUEL ELEMENT SHIPPING CONTAINER (GE MODEL RA-1)



Approximate:

Length	5.5 meters
Diameter	1 meter
Weight	
empty	2 tons
loaded	3.7 tons

FIGURE 2
PWR FUEL ELEMENT SHIPPING CONTAINER

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 75 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 1-7 PWR elements, or 2-18 BWR elements. The casks would be generally cylindrical in shape, and perhaps 5 feet in diameter and 15 to 18 feet long. A recently designed cask of this type is shown in Figures 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/hr) produced by radioactive decay. Water is usually used in the central cavity as a heat medium or primary coolant to transfer the decay heat from the fuel elements to the body of the cask. The heat is usually dissipated by natural processes to the air 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 pumps the heat out and into the atmosphere. Reliable, redundant systems are used where such mechanical systems are relied upon to ensure adequate cooling. [12]

High-Level Nuclear Waste. At the present time, the AEC 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.

Shipping containers for high-level waste shipments will be 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

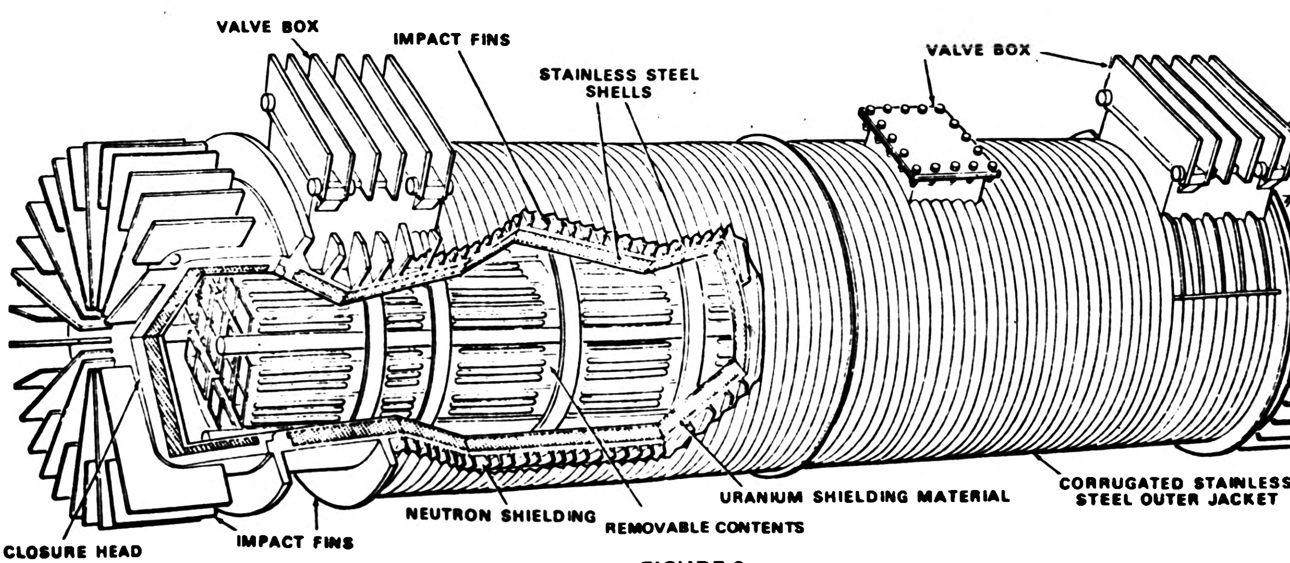


FIGURE 3
SHIPPING CASK

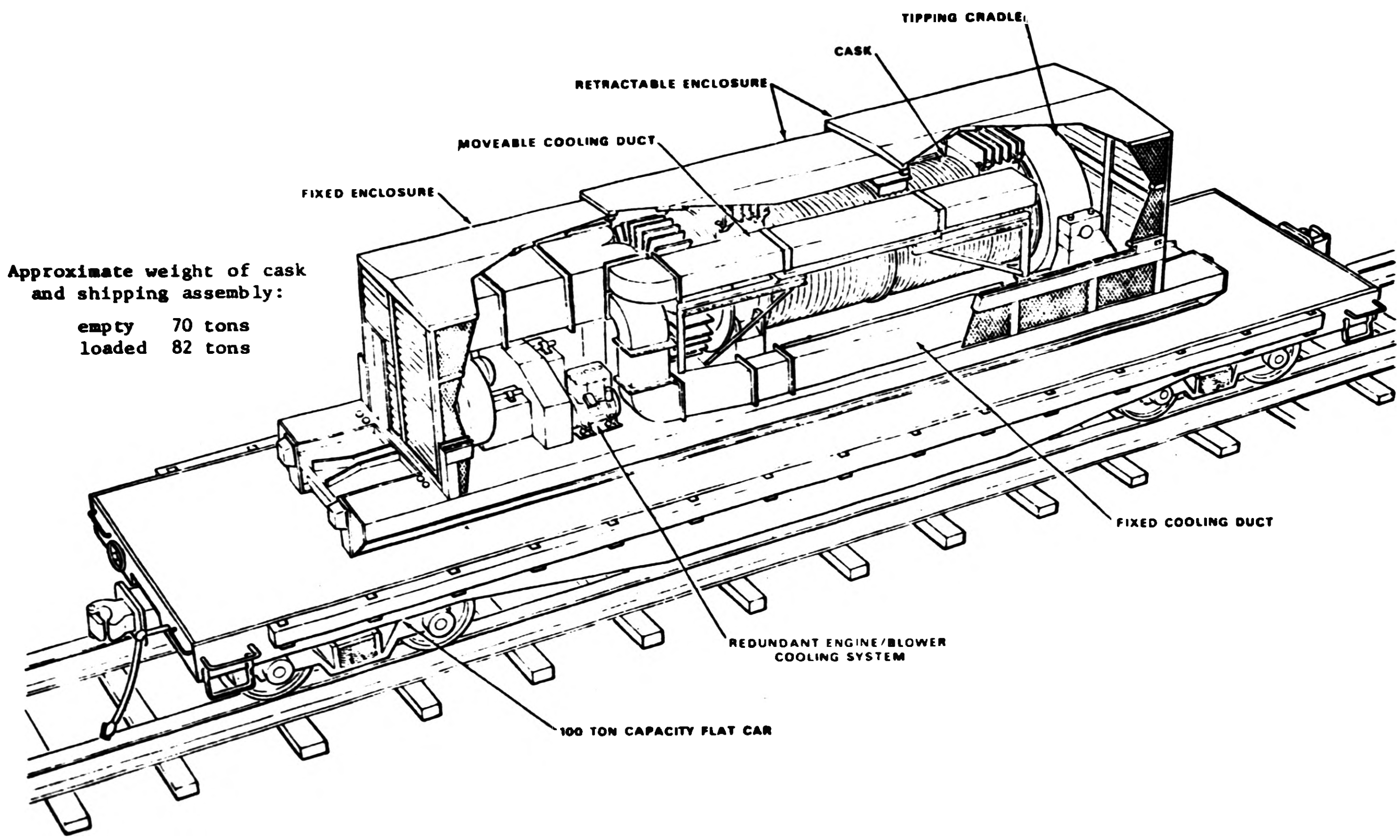


FIGURE 4
IRRADIATED FUEL CASK ON RAIL CAR

reprocessing site. Spent fuel is very similar in its overall shipping characteristics to canisters of high-level waste in that it is highly radioactive and generates 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 burial capsule or canister within the outer shielded cask. The waste is inert, immobile, solid material which is nonexplosive, noncombustible, and cannot turn to gaseous form and become airborne. These high-level waste casks would be transported by rail on conventional heavy duty flat cars. Highway load limits, rather than safety reasons, will restrict highway shipments.

No detailed cash designs have yet been submitted by industry for AEC approval, since shipments to a storage facility will probably not begin until the early 1980's. [18]

Low-Level Nuclear Waste. Under the DOT regulations, [7] 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 pounds. 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.

Alpha Waste. Alpha waste is shipped either in a large accident proof box or in a bundle of 55-gallon drums encased in some sort of outer protective container to protect such materials from impact and fire. Special railroad cars already constructed have been used to transport the solid alpha wastes to a storage facility. Other methods and modes of transportation may be used in the future.

Number of Shipments

Pattern of Shipments. Shipments would be nationwide, with the predominance in the east. Reactor locations as of Dec. 31, 1973, are shown on Figure 5. Fuel processing plants are located in New York, Illinois, and South Carolina. Fuel fabricators are scattered throughout the east. Commercial waste burial sites are in New York, Tennessee, Illinois, Nevada, Washington, and Kentucky.

Fresh Fuel. Each year, on the average, about 1/3 to 1/5 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 6 truckloads of fresh fuel elements would be shipped to a reactor each year. For 100 reactors, that's 600 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 100 reactors, that's 1,000 rail shipments or 4,000 truck shipments per year.

Radioactive Waste from Reactors. About 4,000 cubic feet of low level waste per year would be shipped from a BWR, and about 1,000 cubic feet per year from a PWR. Most of the shipments would be made by truck. About 2,000 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.

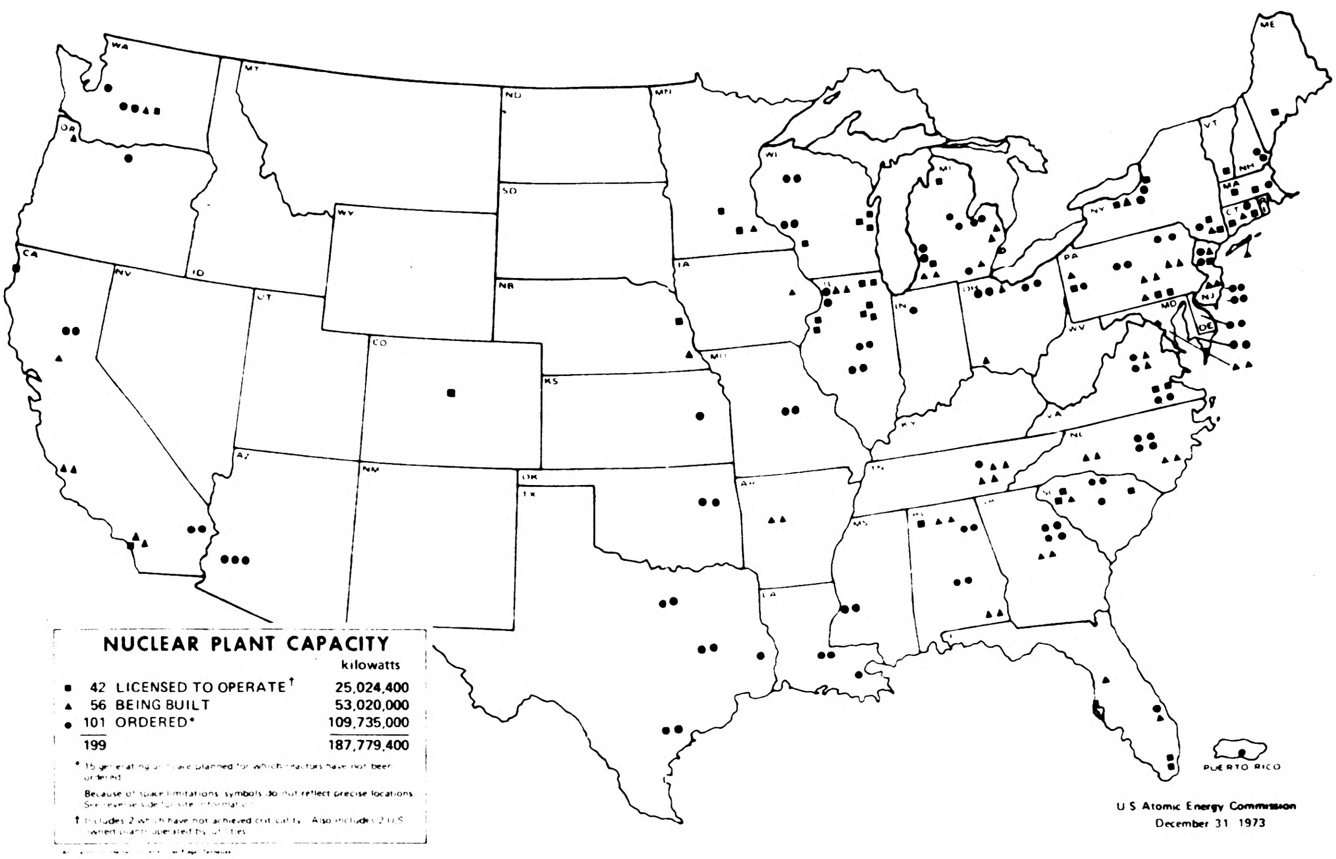


FIGURE 5
NUCLEAR POWER REACTORS IN THE UNITED STATES

Radioactive Waste from Reprocessing Plants

High-Level Waste. 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 will be 260 shipments per year, for the three reprocessing plants. [18]

Low-Level Waste. Each reprocessing plant is expected to produce about 20,000 cubic feet of low level waste per year. There would be about 700 truckloads each year for three reprocessing plants.

Alpha Waste. Each reprocessing plant is expected to produce about 5,000 cubic feet of alpha waste per year. This would be about 30 rail carloads or 150 truckloads each year for three reprocessing plants.

Accidents

Accidents occur in a range of frequency and severity. Most accidents occur at low vehicle speeds, but the severity of accidents is greater at higher vehicle speeds. Most severe accidents generally involve some combination of impact, puncture, and fire effects. Even if the hazardous nature 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 1969, motor carriers reported [13] a total of about 39,000 accidents, 20,000 injuries, and 1,500 deaths. The injury rate is about 0.5 injuries per accident, and the death rate is about 0.03 deaths per accident. The accident rate for hazardous materials shipments was about 1.7 accidents per million truck miles.

Assuming 100,000 truck miles per year of transportation for each nuclear power plant, there would be about 0.09 injuries per year and 0.005 deaths per year per reactor. Those deaths and injuries would be from conventional or common causes not related to the radioactive nature of the cargo.

The nonnuclear property damage rate is about $2,000 per truck accident. With 100,000 truck miles per year per reactor, this would be an average loss of about $300 per year per reactor due to nonnuclear causes.

Rail Accidents. In 1969, the rail industry reported [14] about 8,500 accidents, 23,000 injuries, and 2,300 fatalities. The accident rate for rail accidents was about 1.4 accidents per million car miles.

There were about 2.7 injuries per accident and about 0.27 deaths per accident. Assuming about 15,000 rail car miles per year per reactor, there would be about 0.06 injuries and 0.006 deaths per year per reactor, from conventional and common causes.

Nuclear Materials. To date, there have been no injuries or deaths of radiological nature due to the transportation of nuclear materials. [5] 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. [2]

In recent years, DOT has recorded [2] an average of 40 to 50 incidents per year involving the transportation of nuclear materials. Almost all of these incidents involved Type A or exempt packages. In about 2/3 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 together 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 includes insurance premiums. However, all of 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 AEC completed a study [17] of this type of comparison for nuclear reactor power plant transportation.

Accident Records. In estimating the radiation risk from accidents involving shipments of nuclear materials to and from nuclear power plants, one must consider: (1) the frequency and the severity of accidents; (2) the likelihood of package damage or failure; (3) the nature, amount, and consequences of releases of radioactivity during an accident; and (4) the capacity of coping with such releases.

The environmental effects [5] which might occur in transporting nuclear fuel and solid wastes resulting from the operation of a "typical" power reactor has been evaluated. [17] The risk analysis covers transportation of: (1) fresh fuel from a fabrication plant to a reactor by truck; (2) spent fuel from a reactor to a fuel reprocessing plant by truck, rail or barge; and (3) solid wastes from a reactor to a radioactive burial site by truck or rail. The range of known distances between various sites must be considered. Estimates may be made of radiation effects on the environment under normal conditions of transportation and for credible severe accidents. The potential accidents may be 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 may be estimated.

Normal Conditions. According to the AEC analysis, [17] truck drivers and freight handlers would normally receive an average of about 0.2 to 0.3 millirem per shipment of fresh fuel. No member of the general public is likely to receive more than about 0.005 millirem per shipment. Most of the general public's exposure 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 get during a year would then be perhaps 0.01 millirem or about 1/50,000 of his annual permissible exposure.

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

Accident Probabilities

A study of accident probabilities [16] showed that the frequency of severe accidents for both truck and rail shipments is about one for each one hundred million truck miles or rail car miles. The probability of extremely severe accidents is about 100,000 times less. Considering the total number of truck miles or rail car miles involved per reactor and estimating the predicted accident response of packages, the study [16] shows that the predicted likelihood of serious leakage arising from accidents involving packages of nuclear materials to or from a nuclear power plant in any one year is about one in five million. By comparison, the likelihood of serious injury due to an automobile accident per person per year is about one in 500.

The study [16] also shows that, in the transportation of nuclear materials, the probability of injury or death due to common accident causes is at least 100,000,000 times greater than the probability of injury or death due to radiological consequences. Correspondingly, the total property and cleanup loss from nonnuclear common causes in transportation accidents is expected to be about $300, or about 2,500 times greater than the probable losses from radiological contamination. The total expected average loss from contamination in transportation per reactor year is about 12 cents.

Conclusion

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 (1) determinable, (2) not zero, and (3) very small. In projecting the total accident probability for transportation of radioactive materials to and from nuclear power plants, it seems obvious that the 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 which others force 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 (1) determinable, (2) not zero, and (3) 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 AEC 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, 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 the studies which have been done, it is the AEC's opinion [18]that, with regard to nuclear shipments:

a. We have enough facts and figures on the hazards to allow a more objective evaluation of the risk acceptability than we might derive solely from "gut" feelings.
b. The risk of public catastrophe has been eliminated by strict standards, engineering design safety, and operational care. Whatever the consequences of an accident are, the public hazard will be manageable, and the nuclear effects will be small compared to the nonnuclear effects.
c. 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.
d. 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 apparently have accepted as a way of life without much public support for reduction of risk.

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