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SHIPMENTS OF NUCLEAR FUEL AND WASTE...

are they really safe ?

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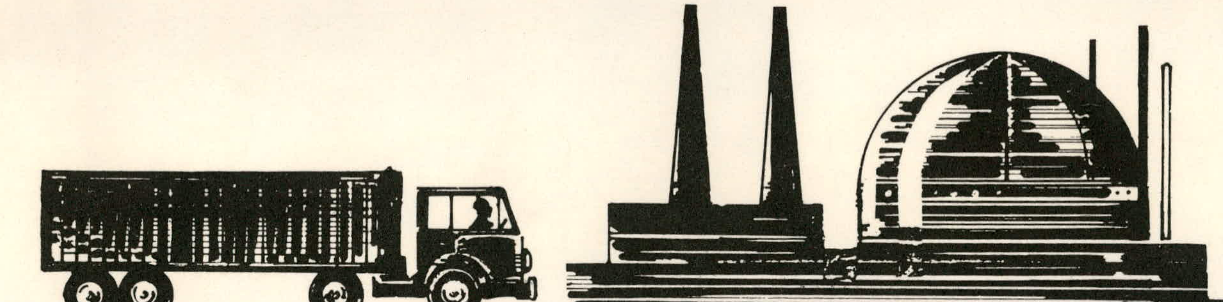

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SHIPMENTS OF NUCLEAR FUEL AND WASTE . . ARE THEY REALLY SAFE?

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. 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.

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 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? 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, existing Government fuel reprocessing plants, commercial fuel storage facilities, and possible future reprocessing plants. This paper presents a summarized status report on 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 be a threat of death or 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 consequences of an accident and its probability, both aspects are presented so that each of us can make up his or her own mind whether the risk from nuclear shipments is acceptable.

What is Shipped?

Nuclear power may play an increasingly important role in meeting the Nation's electrical requirements. If this happens, 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" or "partly spent") fuel elements are presently shipped from reactors to fuel storage sites (for commercial power reactor fuel) or Government fuel reprocessing plants (for research reactor fuel and Government power reactor fuel); nuclear wastes are shipped to storage or disposal sites.

Highly radioactive ("high-level") wastes from commercial spent fuel reprocessing are not likely to be shipped between sites in the U.S. until the late 1980's. If at some future time government policy should permit reprocessing of commercial nuclear fuel, solidified high-level waste from reprocessing will be shipped. Also, solid high-level wastes from existing Government reprocessing plants for national defense nuclear materials will eventually be shipped to the repository.

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 Department of Energy (DOE) 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 Nuclear Regulatory Commission (NRC) has estimated [2] that there were nearly 2,500,000 packages of nuclear materials shipped each year in the United States in 1975. About 80 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 1975 probably numbered only a few thousand. By the year 2000, the number of shipments to and from nuclear power plants will probably increase by perhaps five to ten times the 1975 level [3].

Most 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, or "low boys" over highway, or on heavy duty flat cars 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–from the viewpoints of possible exposure of people to radiation, contamination of property, and overall effect on the environment. Because of the research studies on the hazards of nuclear materials, their properties are better understood than the properties of many other hazardous materials being transported in far greater volume.

Principles of Nuclear Shipment Safety

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

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 nuclear shipments move in routine commerce, and on conventional transportation equipment, they are, therefore, subject to normal transportation accident environments just like other nonnuclear 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. 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. [4] 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 (Type A and B) are required to completely retain their contents during normal conditions of transportation. Materials which contain very low concentrations of radioactivity may be shipped in normal industrial packages, such as wooden boxes or steel drums. For these and other reasons, the chances of an accident releasing serious amounts of nuclear materials are essentially zero [5].

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 Department of Transportation (DOT) [6] and the NRC. [7] 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. [8]

In addition, the packages must provide adequate radiation shielding to limit the radiation exposure to transportation workers and the general public. For spent fuel and high-level nuclear wastes, the packages must dissipate heat to release radioactive decay heat. For both fresh and spent fuel, packages must be designed to prevent nuclear criticality under both normal transportation and severe accident conditions.

Package designs are reviewed by the NRC prior to use in order to verify the adequacy of the design. If the package meets the regulatory requirements, the NRC 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 could 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. Good quality assurance programs increase the likelihood that such errors would be detected and corrected prior to use. The regulations [7] impose certain quality assurance requirements on both shippers and package manufacturers. The shipper is required to determine that each package meets the approved design specifications. All of these things limit both the likelihood and the results of a release during both normal conditions and accidents.

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 over a large 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 nuclear wastes. Nuclear wastes which are shipped around the country to various processing, storage, or burial sites fall into three general categories: (1) low-level wastes; (2) high-level wastes; and (3) other wastes. [9] Each type requires different types of packaging.

Low-level wastes 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 to eliminate a nuisance. Under U.S. and international regulations, low level wastes 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 or objects.

High-level wastes are solidified wastes from the reprocessing of highly irradiated nuclear reactor fuels. The present federal policy is that reprocessing of commercial power reactor fuels shall be postponed indefinitely, and that spent reactor fuel shall be stored at designated storage facilities. For that reason, high-level wastes are currently produced only in Government plants for processing fuel from research reactors, military power reactors, and defense materials production reactors. These wastes have such a high radioactive content of long-lived isotopes that they require long-term storage in isolation. Eventually these wastes, now stored mostly in liquid form in large tanks, will probably be solidified and shipped to a geologic disposal site. The radiation level will be high enough to produce considerable heat, and the material must be heavily shielded, just as for spent fuel elements. The waste will be inert, immobile, solid material which is nonexplosive, noncombustible, and incapable of turning into gaseous form or becoming airborne. Only solid high level wastes would be shipped in any significant quantity since the geologic disposal sites to be operated by DOE would not be equipped to handle and store liquids.

Transuranium (TRU) 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. However, because of the long life and biological toxicity of plutonium, and its potential for causing contamination of people or objects if released from its containment, TRU wastes (above certain minimal levels of radioactivity) require "accident-proof" packaging.

Other wastes are predominantly of the beta-gamma type (e.g., fission product, industrial isotopes) which usually requires some shielding materials as a part of the package. This waste may also be a combination of low-level, 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.

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Package Integrity

Before a specific design of Type B package is approved by the NRC 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 encounter in a hypothetical severe transportation accident. The accident damage test sequence specified in the DOT and NRC 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 2-4 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 rigorously evaluated by the NRC before use. Only if the packaging has successfully passed such 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] 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 fuel element containers are shown in Figures 1 and 2 for Boiling Water Reactors (BWR) and Pressurized Water Reactors (PWR).

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 exchangers with cooling coils running into the body of the cask remove the heat. Reliable, redundant systems are used where such mechanical systems are relied upon to ensure adequate cooling. [11]

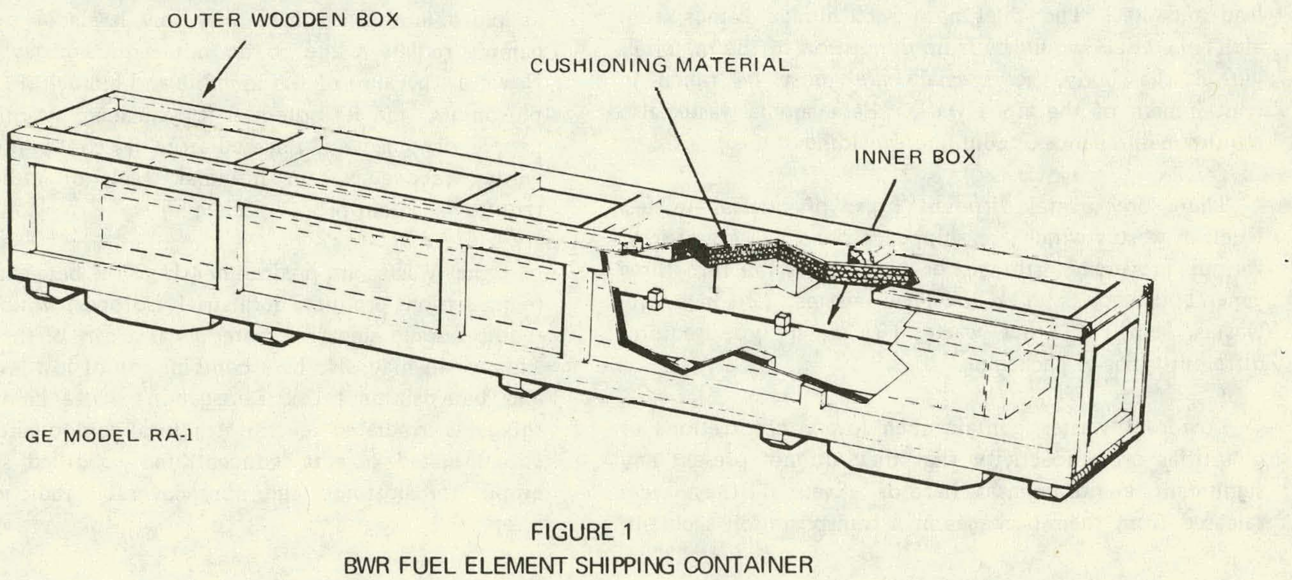

FIGURE 1
BWR FUEL ELEMENT SHIPPING CONTAINER

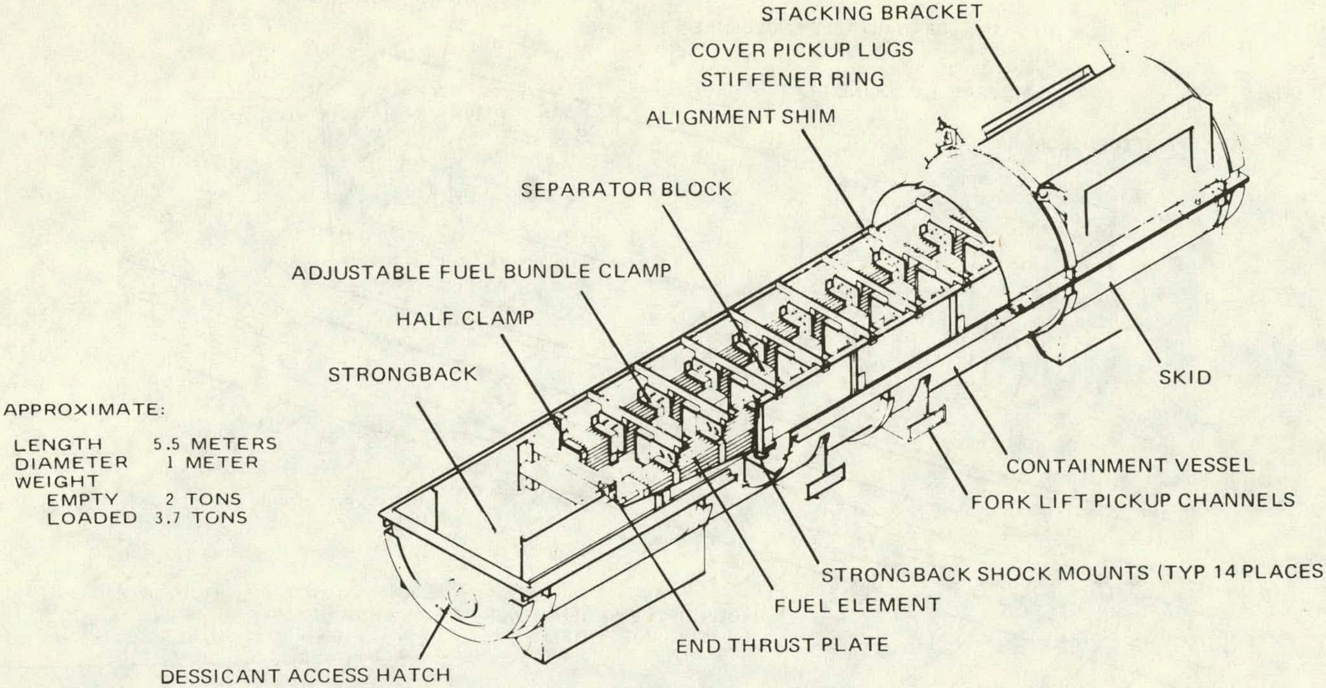

FIGURE 2
PWR FUEL ELEMENT SHIPPING CONTAINER

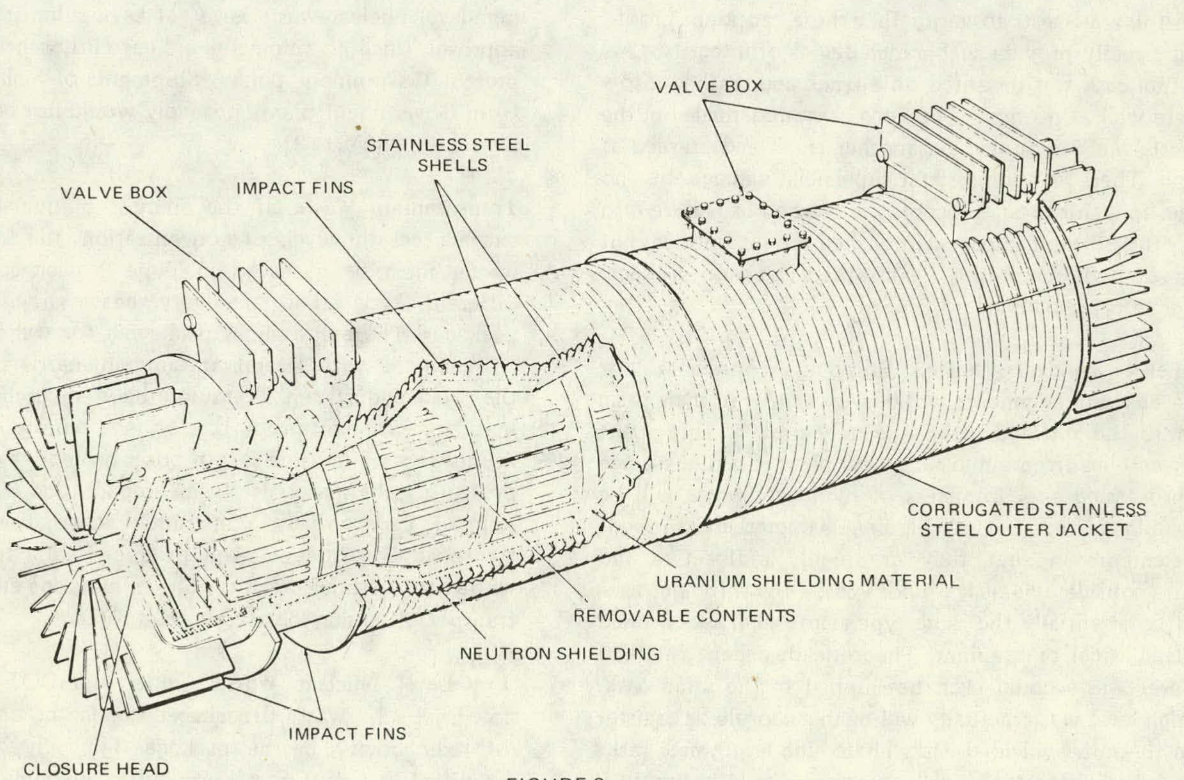

FIGURE 3
SHIPPING CASK

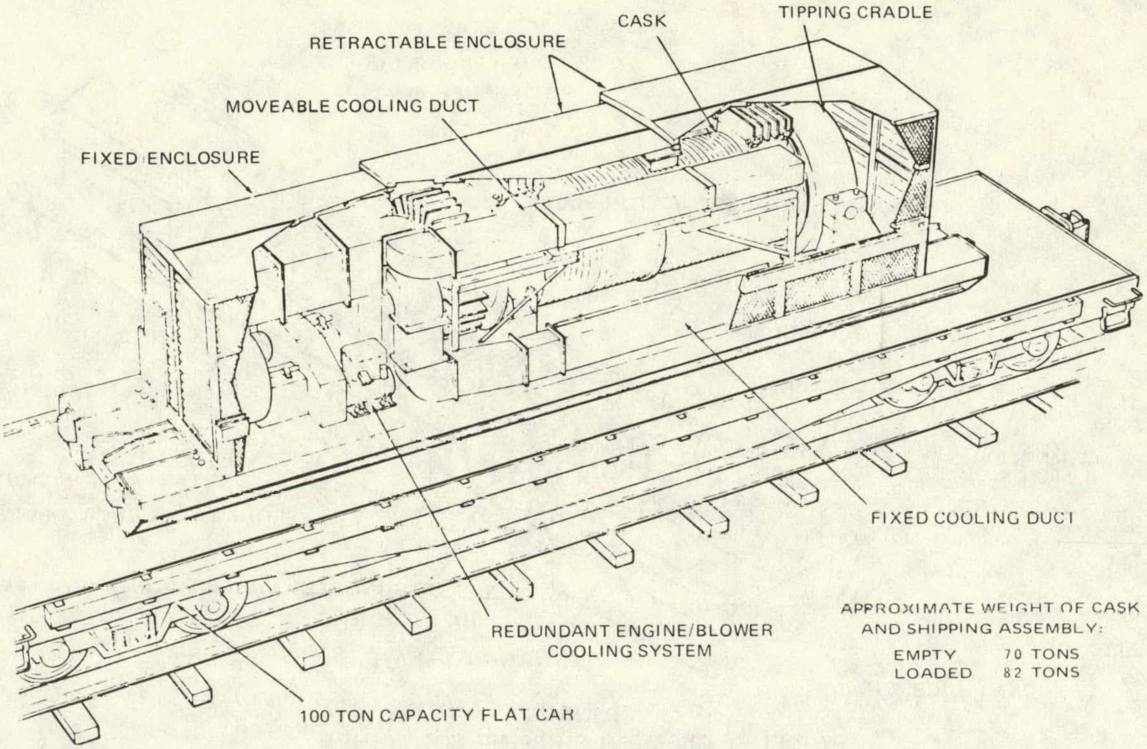

FIGURE 4
IRRADIATED FUEL CASK ON RAIL CAR

In 1977, the Energy Research and Development Administration conducted numerous scale model tests and several full-scale tests to verify that these "accident-proof" packages really provide such a high degree of integrity. One spent fuel cask was mounted on a truck and crashed into a concrete wall at 60 mph. The same cask, undamaged in the first test, was remounted on another truck and crashed at 80 mph. There was some slight superficial damage, but no leakage. In a third test, a locomotive crashed broadside into a cask; the 80 mph impact demolished the locomotive, but hardly dented the cask. Again, there was no leakage. Further tests are planned.

High-Level Nuclear Waste. 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 storage or reprocessing site. Canisters of high-level waste will be very similar in their 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. Theoretically, spent fuel and high-level waste could even be shipped in the same cask. 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 flat cars. Highways load limits, rather than safety reasons, may restrict highway shipments.

A picture of a conceptual design of a high-level waste cask is shown in Figure 5. No detailed cask designs for high-level nuclear waste have yet been submitted for NRC approval, since no shipments are currently scheduled under present Government policy. Shipments of high-level waste from Government plants probably would not begin until at least late 1980's. [12]

Transuranium Waste. If the amount of nuclear materials exceeds certain levels of concentration, the transuranium 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. Transuranium 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 Government plant produced solid transuranium wastes to a storage facility. Other methods and modes of transportation may be used in the future.

Low-Level Nuclear Waste. Under the DOT regulations, 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

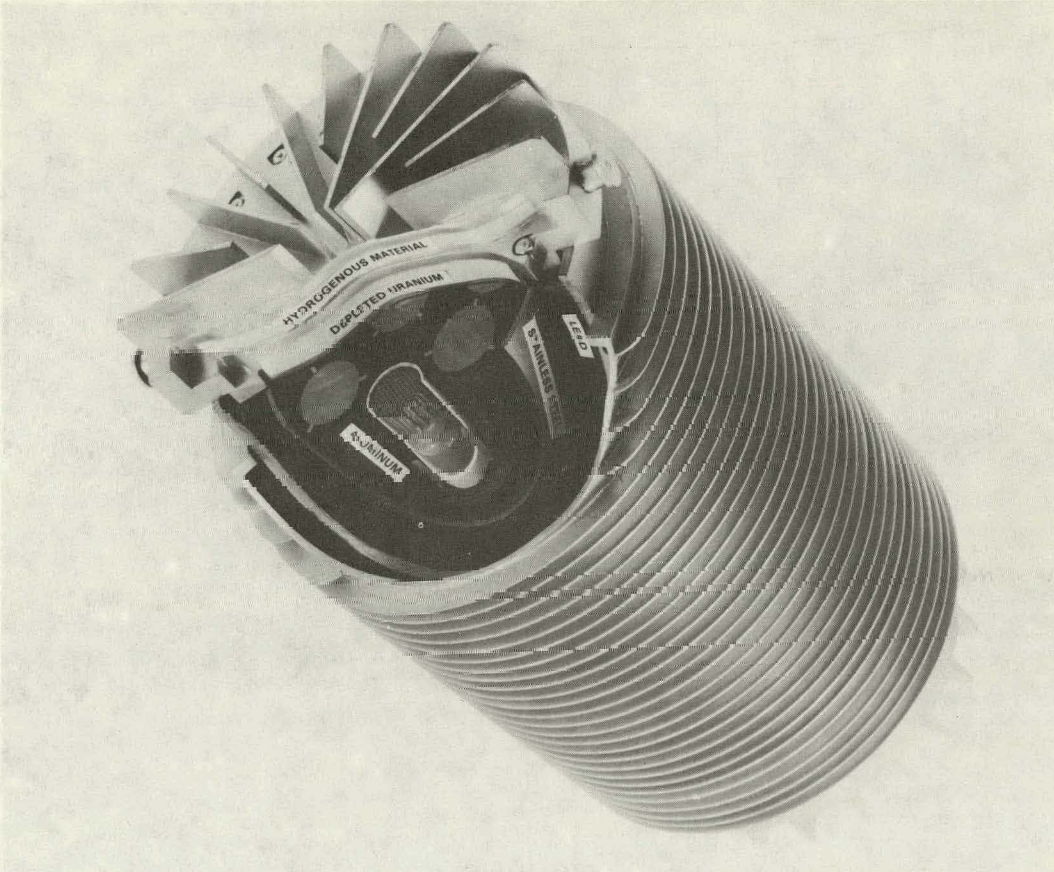

FIGURE 5
CONCEPTUAL DESIGN FOR HIGH-LEVEL WASTE CASK

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.

Number of Shipments

Pattern of Shipments. Shipments would be nationwide, with the predominance in the east. Reactor locations as of December 31, 1976, are shown in Figure 6. Fuel fabricators are scattered throughout the east. Commercial waste burial sites are in South Carolina, Illinois, Nevada, and Washington. Government fuel reprocessing plants are located in South Carolina, Idaho, and the state of Washington. Government fuel reprocessing plants are not now used to process fuel from commercial power reactors.

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 200 reactors, that's 1,200 truckloads per year nationwide.

Spent Fuel. At present, spent fuel is being shipped in the U.S. primarily from research reactors and military power reactors. Small amounts of commercial power reactor fuel are moving now, and larger amounts are expected to be shipped beginning in the early 1980's. All present shipments move across the U.S. by either truck or rail. Some barge shipments may be made in the future. A 1,000 megawatt commercial power reactor generates enough spent fuel to require an average of about 10 rail shipments or 40 truck shipments annually to a spent fuel storage facility. For 200 reactors, that's 2,000 rail shipments or 8,000 truck shipments each year.

High-Level Waste. At the present time, DOE is planning on long-term disposal of all high-level wastes at a federal waste repository. Government reprocessing of spent fuel from military and research reactors has already produced and will continue to generate high-level waste which will be stored for now at the reprocessing sites. So there will be no

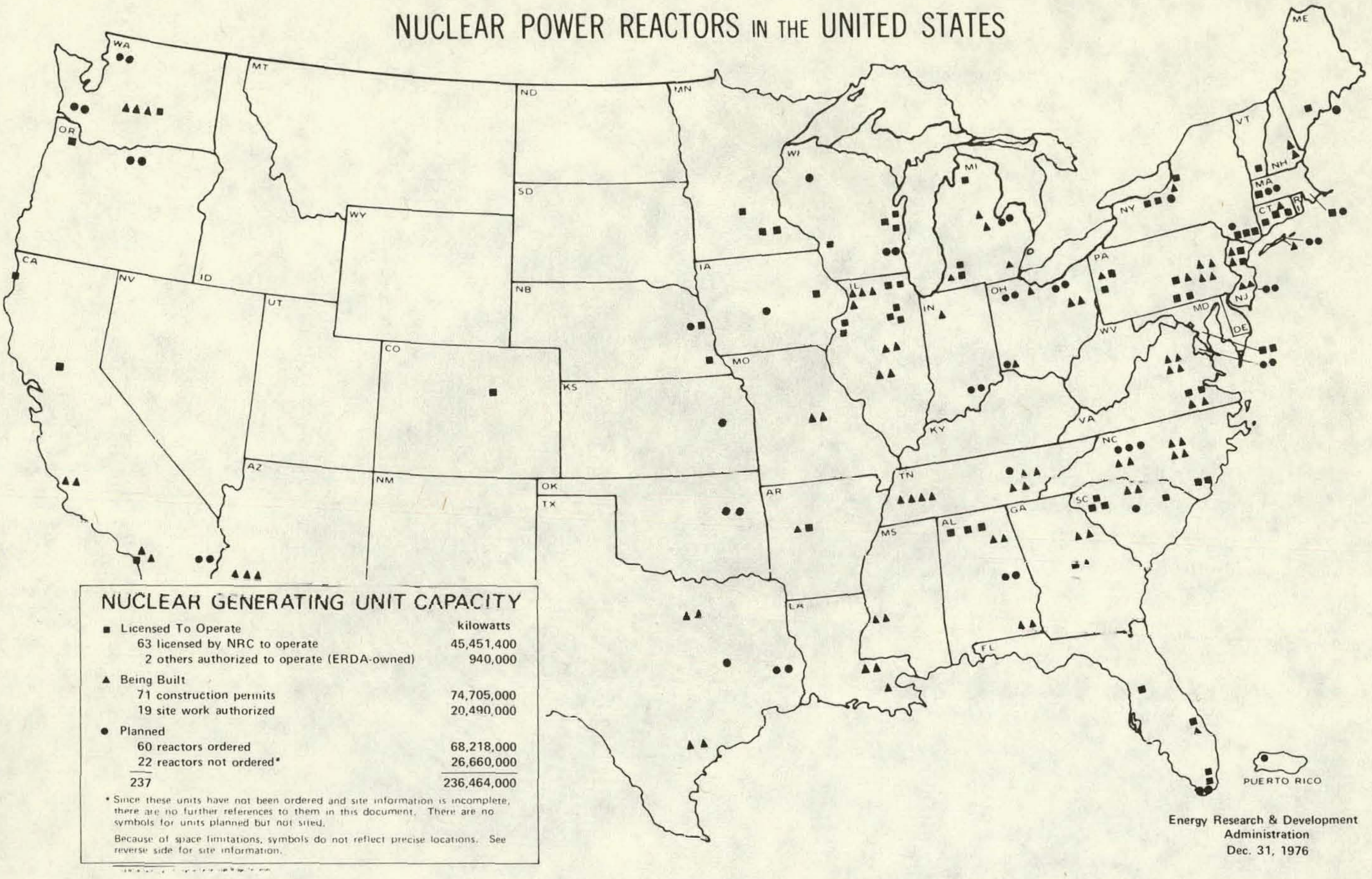

FIGURE 6

shipment of high-level waste in the immediate future. Some intermediate level fission product wastes may be further treated for separation into high-level and low-level components. The former would be shipped to a Federal repository, and the latter to commercial burial facilities.

Low-Level Waste. 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

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 1972, motor carriers reported [13] a total of about 64,500 accidents, 29,000 injuries, and 2,100 deaths along with 132 million dollars 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 all shipments was 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 [14] about 7,500 accidents, 18,000 injuries, and 1,950 fatalities. The accident rate for all 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 a radiological nature due to the transportation of nuclear materials. 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 8,000 to 9,000 incidents per year involving the transportation of hazardous materials of which 15 to 20 involve 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. [15]

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 [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 1977, the NRC completed a study [5] 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: (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 for 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. [17] That risk analysis covers (among other things) transportation of: (1) fresh fuel from a fabrication plant to a reactor by truck; (2) spent fuel from a reactor to a fuel storage site by truck, rail or barge; and (3) low-level 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 NRC 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 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 millirem, 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 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.

Frequency and Severity of Accidents. Based on the DOT accident statistics [14, 15] 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 9 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 rail car 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, those deaths and injuries would not be related to the nuclear nature of the shipments.

The NRC and DOE environmental studies [5, 17] 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 5 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 AEC study [18], 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 been occurring 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, even more severe accidents will probably cause no cask failure. A few percent of severe accidents could 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 [19], costing upwards of $50,000 to clean up.

How about the case of the "impossible" accident-one so violent that the cask shell would be ruptured? First of all, the damaging effects of a gross leakage, should it occur, would be local, not widespread. If it were possible for a high level nuclear waste canister or a spent fuel assembly to be removed from its cask enroute and left exposed, it could cause death (400 rem exposure assumed) to people within 100 feet, but only if they were to remain there for an hour or more. [10] Shorter exposures would kill fewer people; longer exposures would kill more. Serious injuries (150 rem exposure assumed) could result from one hour exposures out to perhaps 150 feet. Beyond 350 feet, there would probably be no radiation injuries at all, and certainly no deaths. There have been some claims that such accidents would cause tens of thousands of deaths. Detailed studies by DOT, NRC, DOE, and others show clearly that those claims are not true. First of all, it is impossible that there would be so many people within 100 feet of any crash scene resulting in a major breach of the cask. Even if there were hundreds there at first, having come running at the sound and sight of a wreck, a probable fire would drive them away beyond hazardous levels. 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 would be 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 a hundred feet or so, and for another hundred feet down wind, but the radiation levels would quickly taper off within about 350 feet to non-dangerous levels. The cleanup of that area would present large but manageable problems, and costs could run as high as a few million dollars, and would require massive cleanup actions, [5] just as when tank cars of poisonous or corrosive liquids have ruptured.

Conclusions

On the basis of the studies referred to, it has been shown that the probability of death, injury, or massive property loss due to transportation of radioactive materials is very small. In projecting the total accident probability for transportation of radioactive materials to and from nuclear power reactors and fuel storage sites, 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 suggest that the likelihood of a catastrophic nuclear transport accident is infinitesimal.

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 individuals' judgments are not especially rational. About 50 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. Often, the acceptability is based on subjective 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 NRC 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." [20] As a result of the studies which have been done, it seems evident 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, for all practical purposes, 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 falls.

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