Safe Transportation of Spent Nuclear Fuel

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Eugene E. Voiland[1]

Recently Congress approved the Yucca Mountain site in Nevada for the disposal of High Level Nuclear Waste (HLW), which includes spent nuclear fuel.[2] The U.S. Department of Energy is now authorized to seek licensing of the repository.

Because spent nuclear fuel is highly radioactive and therefore dangerous, it is a common misconception that its transportation from the nuclear reactor where it originates to the disposal site in Nevada will pose a great hazard and grave risk to the general public.

However, many materials are dangerous under some circumstances, but by simple control measures, the risks can be eliminated or reduced to acceptable levels.

Ammonium nitrate, for example, is used safely by the ton as a fertilizer. On the other hand, it can be a terrible explosive.

Just so with spent nuclear fuel. If no provision is made to control the radiation, it is truly "deadly" and exposure at close range for relatively short periods of time can be lethal.

Fortunately, control of the radiation is done rather simply, by storing or manipulating the spent fuel under water or behind thick layers of iron, lead, or concrete. These "shielding" materials absorb the radiation and eliminate the risk inherent in the unshielded spent fuel.

Thick-walled containers to absorb radiation during transport of spent fuel have been used from the first such shipment in 1946 to the present time, during which several thousand shipments have been made. No container in normal use or involved in an accident has released any of its contents, nor has any increase in emitted radiation above levels allowed by the design ever been noted.

Shipping containers (casks) for the transport of spent nuclear fuel are designed,

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[1] Member of the Center for Reactor Information (CFRI)
The author has had personal managerial experience with the safe transportation of spent nuclear fuel in over 500 truck shipments and over 100 railcar-shipments of spent fuel with no accidents and no consequences to the public. He believes that the existing procedure for shipping spent fuel is a well established and safe procedure that has proven more than adequate over the test of time.

[2] Nuclear fuel is the uranium material that undergoes a nuclear reaction in a nuclear reactor to produce heat and steam for the production of electricity. “Spent” nuclear fuel is, for a variety of reasons, no longer useful to sustain the nuclear heat-generating reaction. The spent fuel can be thought of as the “ashes” of the nuclear reaction. Spent fuel is exceedingly radioactive, is inherently dangerous, and must be handled with great caution.

fabricated, and operated under regulations prescribed by Title 10, Part 71, Code of Federal Regulations, "Packaging and Transportation of Radioactive Material." Such casks are strong, massive metallic cylinders that are designed to retain their contents under the most unlikely accident conditions. These casks are inherently safe containers for transporting large quantities of highly radioactive materials including spent nuclear fuel.

Exposure of the public to radiation while the cask is in-transit is inconsequential.

The transportation section of the U.S. Department of Energy's "Environmental Impact Statement (EIS) for Yucca Mountain" considers the frequency that accidents can occur, their severity and their consequences,[3] *both radiological and nonradiological. It concludes that in more than 99.99 percent of rail and truck accidents no cask contents would be released. Hypothetical accidents that could cause damage to a cask are very serious, very improbable, and expected to occur extremely infrequently. One such postulated accident could be expected to occur three times in each trillion truck accidents, a second such accident, three times in 100 trillion accidents.*

Confidence that casks will perform as designed arises from validated engineering analyses and from many tests using scale models and actual casks.

That this confidence is not misplaced is borne out by the performance of casks in actual use.

The record is perfect!

> *"The safety record for spent fuel shipments in the U.S. and other industrialized nations is enviable. Of the thousands of shipments completed over the last 30 years, none has resulted in an identifiable injury through release of radioactive material."* [4]

* * * *

A reliable transport system for the movement of spent nuclear fuel was recognized very early as an essential part of the process of making electricity from nuclear energy. Originally, it was expected that the spent fuel would be moved to a reprocessing plant for recovery of recyclable nuclear fuel materials and packaging of the radioactive waste ma-

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[3] "Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel... DOE/EIS-0250", U.S. Department of Energy, Office of Civilian Radioactive Waste Management. February 2002.

[4] As cited in the Congressional Research Service Report for Congress, "Transportation of Spent Nuclear Fuel." Updated May 29, 1998.

terials for disposal. For a variety of reasons, large-scale commercial reprocessing of the spent fuel did not materialize in the United States. Instead a decision was made to treat the spent fuel as a waste for disposal. The Nuclear Waste Policy Act of 1982 (as amended) specifies that the federal government will take ownership of the spent fuel and assume responsibility for its disposal.

Users of nuclear-produced electricity pay for disposing of spent fuel by a surcharge of a tenth of a cent per kilowatt-hour, which is included in their electric bills.

In July 2002 the Congress approved the site at Yucca Mountain in Nevada as the U.S. repository for disposal of high-level nuclear waste (which includes spent nuclear fuel). The U.S. Department of Energy is applying for site license from the U.S. Nuclear Regulatory Commission.

One concern is that adopting a central location in the western part of the country for spent fuel disposal will require shipping highly radioactive material across the country. According to some, the possible release of spent fuel in a transportation accident is an unacceptable risk.

This report provides information about the safety of the spent-fuel transportation system that has been in use for the past 40 years and under which several thousand spent-fuel shipments have been made with no release of any of the transported materials.

Design Considerations. The chief factor that influences the design of the transport system is the need to protect the general public from exposure to the radiation emitted by the radioactive materials contained in the spent fuel. Thus, the shipping containers for spent fuel have to:

> Ensure that the spent fuel remains contained even under severe accident conditions.
>
> Ensure that radiation levels at the surface of the container are well below allowed limits during normal transport and under accident conditions.
>
> Ensure that the transported spent fuel cannot accidentally undergo a nuclear fission reaction.

From the beginning, it was believed that it was well within technical capabilities to design and fabricate a transport system that meets these performance requirements. It was also believed necessary to provide a regulatory framework to assure that the resulting system would consistently meet performance requirements.

Regulations Affecting Transportation Systems. The basic criteria for packages for shipping high-level nuclear materials and spent fuel originated in 1946 and were based on recommendations of the National Academy of Sciences. These recommendations served as guidance for manufacture of the early shipping casks for spent fuel and have been adopted by the International Atomic Energy Agency and by 53 nations.[5]

Regulations were formalized based on the above criteria and in 1974 the United States Nuclear Regulatory Commission issued Title 10, Part 71, of the Code of Federal Regulations (10CFR71). This directive on the *Packaging and Transportation of Radioactive Material* is a detailed and comprehensive listing of requirements that must be met for safely shipping radioactive materials.

A few of the 75 subjects addressed in 10CFR71 that pertain to spent fuel transport include (i) application procedure for package approval, (ii) the approval standards that a shipping package must meet for irradiated nuclear fuel transport, (iii) the tests that the package must meet, (iv) quality control procedures that apply, and (v) operational procedures to be followed in use of the shipping containers.

In conformance with this regulatory document, a typical spent-fuel container -- generally referred to as a cask -- is a 20- to100- ton cylinder consisting of concentric layers of steel alloy (for strength), a dense metal such as lead or uranium between the steel layers (for absorption of gamma radiation), a neutron shield wrapped around the cask, and a grid-work within the cask to hold the spent fuel. One end of the cask is fitted with a closure and seals capable of maintaining cask integrity under severe impact.

For example, casks for shipping spent fuel to Yucca Mountain are about 20 feet long and about six feet in diameter, depending on design.

Performance Under Accident Conditions. A cask built in conformance with 10CFR71 has proven to be invulnerable to damage from the most serious accidents experienced on the nation's highways or railroads.

In December 1977 the Nuclear Regulatory Commission released its environmental statement on the transportation of radioactive material, NUREG-0170, which concluded that the risks associated with shipment in casks licensed to the standards of 10CFR71 are small.

In February 1987 another comprehensive study was completed.[6] This study relied on historical highway and railroad accident information to define realistic accident scenarios. By applying engineering analyses to casks hypothetically involved in such accidents, realistic assessments of damage were made. The conclusions were that radiological risks are "...less than risks previously estimated in the NUREG-0170 document."

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[5] OTA Report "Transportation of Hazardous Materials", Office of Technology Assessment, U.S. Congress. July, 1986.

[6] Fischer, L. E. et al, Shipping Container Response to Severe Highway and Railway Accident Conditions, NUREG/CR-4829. Lawrence Livermore National Laboratory. February 1987.

In the mid-1970s Sandia National Laboratory conducted impact tests of shipping casks.[7] These tests simulated actual accidents. A highway-transported cask was mounted on its trailer and the trailer was attached to its tractor in the usual fashion. Similarly, a rail-transported cask was mounted on its special rail car and the car attached to a locomotive. These casks containing unirradiated nuclear fuel were subjected to a variety of tests including (i) being impelled by rocket motors at speeds of more than 60 miles per hour into a massive 688-ton concrete barrier backed by 1700 tons of dirt, and (ii) being struck broadside (truck transported cask) by a locomotive. These tests showed that the casks could be expected to retain their radioactive contents "... in extremely severe transportation accidents".

Such accidents are very improbable. The 60-mile per hour highway impact was judged to occur with a probability of once every 70 years assuming seven million transport miles per year for spent fuel. Accidents corresponding to the other test scenarios are considered much less probable with average number of years between accidents ranging from 1,000 to 18,000 years.

Even more important than the demonstration that these cask systems could perform as designed was the confirmation that scale models could be reliably used to predict full-scale performance and that the engineering analytical methods used were valid.

The impregnability of spent-fuel shipping casks is well accepted. For example in a Smithsonian article, the author states "Gasoline...is far and away the most dangerous cargo on the nation's highways. It would be possible to build gasoline trucks that are as well protected as those that haul nuclear fuel, but doing so, the carriers say, would mean paying much more for gas at the pump."[8]

Response to a Fire. Full-scale fire tests[9,10] under extreme conditions disclosed that a cask could be exposed to twice the heat and three times the duration specified by the current regulations before cask degradation occurred. The response of the cask was well predicted analytically. In one test, the lead melted completely and some lead escaped, but no fuel was released. The probability of a railroad cask fire of this magnitude is estimated at once every 700 years.

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[7] Yoshimura, H. Richard, Full Scale Simulations of Accidents on Spent-Nuclear-Shipping Systems. Sandia National Laboratory. Undated.

[8] MacFadyen, J. Tevere, "Routine shipments of essential goods are freighted with special risks", Smithsonian, April, 1984.

[9] Vigil, Manuel, et al. Experimental Program Assessing Thermal Response of a Spent Fuel Transport Cask SAND82-0110C June 1982. (Sandia National Laboratories.)

[10] Eggers, P. E. et al. Thermal Analysis of HNPF Spent Fuel Shipping Container in Torch Environments. July 1980 (Ridalgh, Eggers, and Associates, and Sandia National Laboratories).

Response to a Sabotage Attack. A test to determine the amount of spent fuel that would be pulverized and become breathable if a cask were subjected to explosive penetration was undertaken in late 1981.[11] The results of this experiment in which a 26-ton cask containing a single unirradiated fuel assembly was penetrated by a shaped charge explosive device, disclosed that very little of the fuel was converted to particles of a size breathable by humans.

Using the information garnered in this experiment, an analysis was made of the radiological consequences of a hypothetical accident in which a truck mounted cask containing spent fuel is assumed to undergo such an explosive attack in Manhattan, New York City. The results from nuclear causes were no early deaths (within weeks after exposure), no early fatality (deaths within a year after exposure), and possibly one cancer fatality later. (The study did not speculate on the number of deaths that might result from the explosion.)

Certainly the nuclear effects were inconsequential as compared to homicides or vehicular accidents occurring in the same period in New York City.

Conclusion. A combination of good regulatory standards, good engineering design, quality controlled fabrication and inspection processes, validated performance of scale-model and full scale casks under a variety of test conditions provide a high degree of confidence that containers used for the shipment of spent nuclear fuel will do their job safely, both in normal use and in the event of very serious accidents.

Backup Information

Hypothetical Accident Conditions from 10CFR71.73

A cask for shipment of spent fuel must be able to survive the following tests:

> A drop through 30 feet onto an **unyielding** surface. ("Unyielding" is the main point here, as this ensures that the kinetic energy of the drop is all applied to the cask. We all know that a light bulb will usually survive a fall onto a carpet, but will not live through impact with a concrete floor.) In practice, in addition to the collapsible structural components of the cask system, engineered collapsible "impact limiters" are attached to the casks to provide a "yielding" surface in the event of accident.
>
> Impact by an 1,100-pound mass falling through 30 feet.

[11] Sandoval, R. P. (Sandia National Laboratories) and Newton, George J. (Lovelace Foundation) A Safety Assessment of Spent Fuel Transportation through Urban Regions. March, 1982.

Fall of the cask from a height of 40 inches onto a steel post 6 inches in diameter and 8 inches long.

Exposure to an engulfing fire at 1,475 degrees Fahrenheit for 30 minutes.

Immersion under three feet of water. (An undamaged specimen of the cask must not leak when immersed to a depth of 50 feet -- or a pressure equivalent of 21.7 pounds per square inch.)

Orientation of the cask in each test is to be such as to assure maximum damage. The impact tests are to be applied successively, followed by the fire and water tests. Thus the cask must maintain its integrity through all of these tests.

Spent Nuclear Fuel

Spent nuclear fuel looks just like it did when it was loaded into the reactor. Within the fuel rods there is a change in the atomic species due to fission of uranium and plutonium in the reactor and radioactive decay after removal from the reactor. There is a minuscule loss of weight because in the fission process some mass is converted into energy (heat).

Typically, nuclear fuel[12] consists of ½-inch diameter by ½-inch long ceramic uranium dioxide pellets stacked in 13-foot long tubes of a zirconium alloy. From 63 to 264 of these fuel rods, depending on the particular fuel design, are mounted in metal fixtures. These fuel-rod aggregations are called fuel assemblies.

A large number of fuel assemblies -- containing a total of 120 to 140 tons of uranium[13] -- are grouped in the "core" of the reactor. When the reactor is operating, fission and radioactive decay produce heat mostly within the fuel rods. This heat is transferred to water pumped through the fuel assemblies and the water is directly or indirectly converted to steam. The steam powers turbine-generators that produce electricity.

This is the same way that electricity is usually generated except that the heat is provided by a nuclear reaction rather than by a chemical combustion process such as the burning of coal, gas, oil, or other fuel. A significant difference is that in the nuclear powered system there are almost no gases -- greenhouse or otherwise -- emitted.

The fuel rods remain in the reactor typically for three or four years, in 600-plus degree Fahrenheit water and at a pressure exceeding 1,000 pounds per square inch. In some instances, reactors have run continuously for over a year at essentially full power -- a quite remarkable technical feat. The fuel rods survive this harsh environment very well.

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[12] Table A-18, p. A-25. Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Nuclear Fuel…, DOE/EIS-0250, February 2002.

[13] Typical Boiling Water Reactor. Personal communication Exelon Corporation.

About every 18 to 24 months, one-fourth to one-third of the fuel rods are no longer suitable for continued use in the reactor. They become "used" or "spent" fuel and are removed and replaced by fresh fuel.

Upon removal from the reactor, the spent fuel is stored under water in a basin to allow the short-lived radionuclides to decay to more-stable isotopes and to reduce the heat emitted by radioactive decay.

When a nuclear power plant is shut down, the rate of heat production immediately drops by a factor of 16 to about 6% of what it was when the fission process was ongoing. An hour later, it is down by a factor of 100 to about 1%. After a month, the power reduction factor is about 1,000 (0.1%). After a year it is about 5,000 (0.02%) and after 5 years about 30,000 (0.003%).

Freshly discharged spent fuel is stored in deep pools at the reactor covered by at least nine feet of water. The water provides both shielding from the radiation and removal of heat from the radioactive decay.

After about five years of water storage the heat output of the spent fuel is reduced to the extent that it can be stored in massive concrete containers that are air cooled by convection.

According to federal regulation, the spent fuel is considered to be High Level Nuclear Waste.

Spent Fuel Shipping to Yucca Mountain

Because of the incredible efficiency of the atom as a power source, very little spent fuel is produced each year.

A typical modern nuclear reactor that operates at a 1,000 megawatt electrical power level will use 20 to 30 metric tons of uranium per year[14] and, therefore produce, at the most, 30 tons of spent fuel. This 30 tons of fuel will make about 8,000,000,000 kilowatt-hours (kwh) of electricity. (To get some idea of how much electricity this is, look at the number of kilowatt-hours (kwh) that appears on your monthly electric bill! Possibly 1,500 kwh in the summertime.)

(At an electricity cost of 5 cents/kwh, the electrical output of the 1,000 megawatt reactor represents an income of $400,000,000 per year to the owner of the reactor.)

An annual production of spent fuel would require less than three rail shipments to Yucca Mountain per year, each shipment consisting of a special train of three rail cars, each car containing one cask.

[14] Nuclear Waste. The "About Network", downloaded from the Internet. (An abridged version of a Congressional Research Service Report by Mark Holt, Resources, Science, and Industries Division, April 23, 2001.)

For perspective, to generate this same amount of electricity from coal requires burning about 3,000,000 tons.[15] Transporting this much coal, each year, takes over 300 train loads, each train consisting of over 100 rail cars, each car containing 100 tons of coal -- in all 30,000 car loads.

In 1999 there were about 40,000 tons of spent fuel stored at reactors[8] and in away-from-reactor storage around the country and another 20,000 tons would be produced before Yucca Mountain is ready to receive any spent fuel.

How quickly the spent fuel needs to be removed from the reactors and transported to Yucca Mountain will determine the rate at which the spent fuel will need to be shipped and will require answering a number of questions. The logistics of the spent fuel shipping system, including availability of casks, turn-around time, etc., will determine the most efficient method of operation.

Answering these questions is simply a typical business problem -- one that requires good interfacing between the Yucca Mountain disposal site, the shippers, the railroad, and regulators. Though the transportation process is not simple, it is a routine commercial activity, and many experts will pay close attention in the planning and execution.

Effects of Sabotage Explosive Assault

The risks associated with a sabotage assault on a spent fuel shipment depend on how much radioactive material will be released from the cask as a respirable aerosol. In the earliest regulations there was no empirical information available, so risks were based on speculative scientifically based estimates. A Sandia study, SAND 77-1927 to estimate the radiological consequence of a sabotage event, assumed that 0.07 percent of the spent fuel in the cask could be converted to a respirable form. This value was acknowledged to be very conservative and fraught with uncertainty.

Based on the potential risk that this study suggested, the NRC imposed a number of temporary rules to reduce the chance that such a sabotage event could occur.

Both the NRC and the Department of Energy, realizing that realistic data were needed as a basis for realistic regulations, sponsored experimental programs to pin down the question of how much spent fuel subject to a violent explosive attack would be converted to a respirable aerosol.

Battelle Memorial Institute conducted experiments using actual spent fuel. Sandia National Laboratory conducted a full-scale program using an obsolete shipping cask and unirradiated fuel. The results of these programs complemented each other and it was learned that the actual formation of respirable fraction was very much less than had been estimated in the previous study.

[15] Based on 0.47 tons of coal per 1000 kilowatt-hours.

In Sandia's full-scale test[6] the amount of material in the respirable range was found to be only about 1/10 of an ounce of uranium dioxide from 220 pounds damaged in the spent fuel.. This is about 0.0006 percent of the fuel or less than 1/100 of that assumed in the earlier study.

This full-scale test confirmed that the effect of the explosive charge was to shatter the material affected rather than to pulverize it. This knowledge is also useful in planning for clean-up after such an event should it occur.

In applying this new experimental data to a radiological consequences analysis, it was learned that if such a sabotage event were to take place in Manhattan, New York City, it would result in no early fatality nor morbidity -- apart from the effects of the explosion -- and no more than one later cancer fatality.

Actual Cask Accident Experience

In the CRS Report for Congress "Transportation of Spent Nuclear Fuel" [16] Mark Holt quotes the NRC

> "The safety record for spent fuel shipments in the U.S. and other industrialized countries is enviable. Of the thousands of shipments completed over the last 30 years, none has resulted in an identifiable injury through release of radioactive material."

He goes on to say that in the period from 1979 through 1995, 356 metric tons of spent fuel were shipped in 1,168 highway shipments and 979 metric tons in 138 rail shipments.

During 1971 to 1995 eight accidents involving casks took place, with no release of radioactive material in any of them. In four of these accidents, the casks were loaded with HLW.

- In one accident the truck left the road and the cask was thrown from the trailer. The cask was slightly damaged but was repaired. The driver was killed.

- In two incidents the truck/trailers failed. The casks were undamaged.

- In the fourth accident a train carrying two casks of Three-Mile Island core debris collided with a car. The casks were undamaged.

Environmental Impact Statement

"The purpose of the environmental impact statement (EIS) is to provide information on potential environmental impacts that could result from a Proposed Action to construct,

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[16] Holt, Mark. Transportation of Spent Nuclear Fuel. Updated May 29, 1998. This document is a Congressional Research Service Report for the U.S. Congress.

operate and monitor, and eventually close, a geologic repository for the disposal of spent nuclear fuel..." [17]

The EIS analysis considered the impact of 10,700 rail shipments over a 24-year period using 21 rail-accident cases that ranged from very common accidents to those so very unlikely as to be almost impossible -- "the maximum reasonably foreseeable accident." Latent cancer fatalities from the latter improbable event were estimated to be five for the rail scenario. For this same kind of accident three traffic fatalities were calculated.

Consequences from various collisions, fires, and combinations of collision and fire were examined.

The consequences of an accidental crash of a large jet aircraft into a cask were also calculated. The cask would not be penetrated, but failure of the cask seals would result in a fraction of one latent cancer fatality.

International Spent Fuel Shipping Experience

> "Internationally, more fuel has already been shipped and successfully transported than is scheduled to be shipped to Yucca Mountain." [18]

Existing Spent Fuel Shipment Procedure

Following is an abbreviated description of the various activities that are currently undertaken in the shipment of spent nuclear fuel. This listing may not include every item, but should provide a reasonable understanding of the process.

For simplicity's sake this description deals only with rail shipment, since this is the most likely shipment mode to Yucca Mountain. Currently, rail shipments are made by special train and it is assumed that that policy will continue.

<u>Preliminary</u>.

Advance arrangements are made to assure a compatible schedule between the shipper of the spent fuel (the utility), the receiver of the spent fuel, the provider of the shipping casks, and the railroad.

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[17] <u>Final Environmental Impact Statement for a Geologic Repository for the Disposal of Spent Fuel...</u>DOE/EIS-0250. U.S. Department of Energy. February 2002. Summary, p. S-1.

[18] Nuclear News <u>45</u>, 8 p. 13.

A schedule is made for notification of regulatory and other organizations as may be required.

The route is established and whether it will require armed guards and state notification.

<u>Shipping site activities</u>.

Standard Operating Procedures are prepared and approved.

Site personnel are trained in loading the cask.

Equipment is identified and checked out.

The empty cask is received.

Measurements are made on the empty cask to assure shipping regulations have been complied with.

The cask's personnel barrier is removed, the impact limiter is removed, and the cask moved to the preparation area. It may require cleaning.

The nuts or bolts that hold the cask head on are removed.

The cask is moved to the transfer area of the spent fuel storage pool and the head removed to its temporary storage spot.

Spacers, if needed to adjust for various fuel assembly lengths, are installed.

The spent fuel assemblies are transferred from their storage positions to the grid in the shipping cask.

(All movements of the spent fuel under water must maintain at least nine feet of water over the fuel.)

Fuel identification numbers are recorded for accountability purposes.

The cask head is replaced and the cask removed from the storage pool.

The cask is drained of residual water.

The cask head is fastened down and the cask leak-tested.

Records that all operations were done according to the appropriate Standard Operating Procedures are verified.

The cask is scrupulously cleaned to assure that surface contamination is well below regulatory limits.

The loaded cask is returned to its rail car, the personnel barrier is re-installed and final measurements made to determine radiation levels outside the cask.

Shipping papers are provided the carrier.

Final confirmation is made that all transportation safety requirements have been met.

The cask is tendered to the railroad, which transmits it to its destination.[19]

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Acknowledgments

The author gratefully acknowledges critical reviews by Martin J. Steindler and Richard A. Beatty who have retired from life-long careers in the nuclear field.

Recommended Reading

Congressional Research Services Report to Congress
"Transportation of Spent Nuclear Fuel -- Summary" by Mark Holt, Environment and Natural Resources Policy Division.
Updated May 29, 1998.

[19] Shipments of all hazardous materials are made under authority of the U.S. Department of Transportation. This authority is codified in the Code of Federal Regulations, Title 49, Transportation, Parts 170-179. Routing of high levels of radioactive materials are addressed in a rule commonly referred to as HM-164.

Footnotes/References:

1. Member of the Center for Reactor Information (CFRI).

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5. OTA Report "Transportation of Hazardous Materials", Office of Technology Assessment, U.S. Congress. July, 1986.

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11. Sandoval, R.P. (Sandia National Laboratories) and Newton, George J. (Lovelace Foundation) A Safety Assessment of Spent Fuel Transportation through Urban Regions. March, 1982.

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18. Nuclear News 45, 8 p. 13.

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