TMI Unit 2 Technical Information & Examination Program

UPDATE

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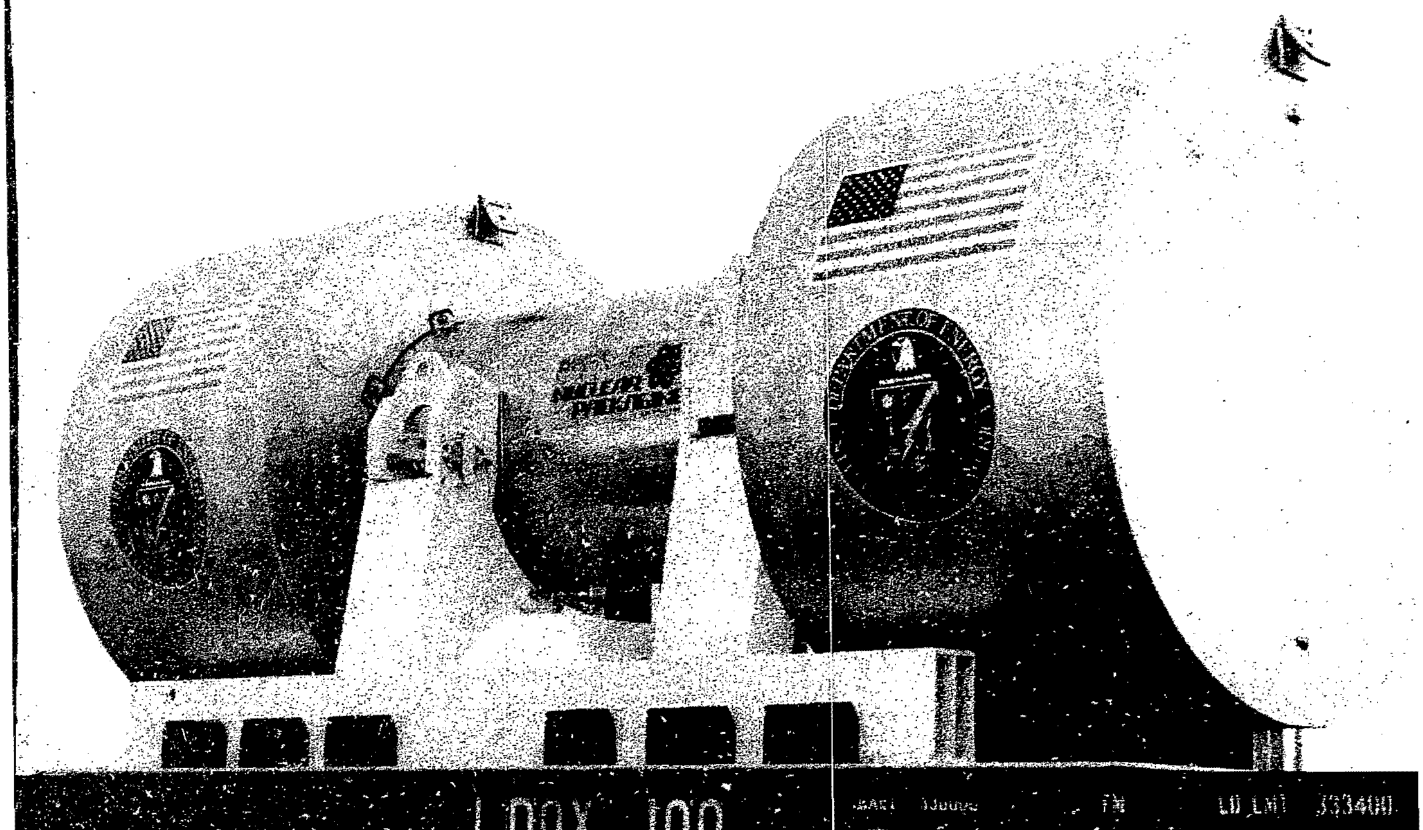
Special cask in place on 150-ton railroad car.



One of the remaining major efforts in the cleanup of the Three Mile Island Unit 2 reactor was the development of a safe, reliable shipping cask to transport the TMI-2 spent fuel debris from TMI to the Idaho National Engineering Laboratory.

Included in this special issue of the ***Update*** *are articles about design and construction of the shipping cask, the extensive testing process for cask certification, procedures for loading the core debris at TMI-2, the transportation process and safety precautions, and plans for unloading, storing, and examining the fuel debris at the INEL.*

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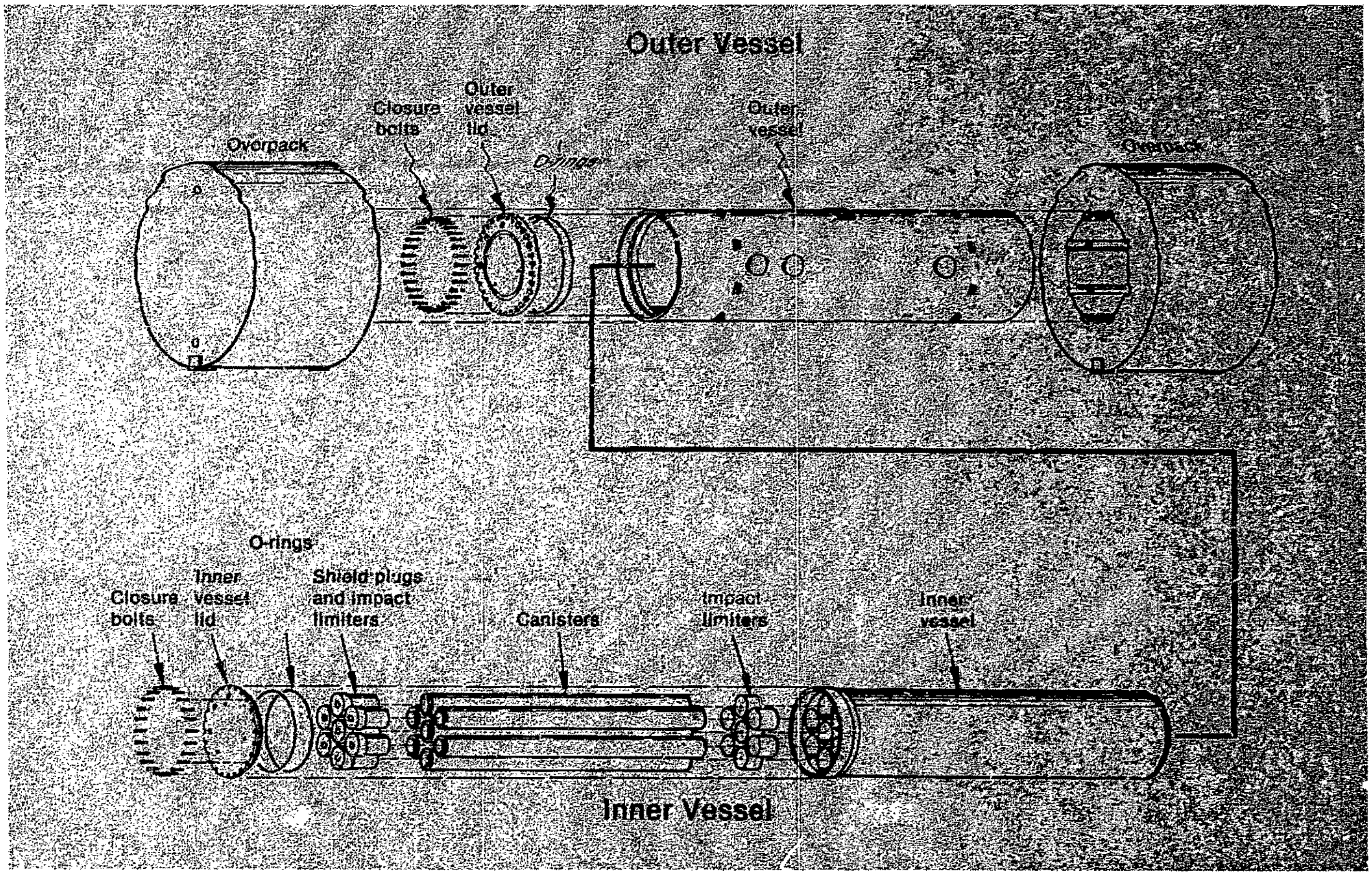
Special Cask Developed for Core Debris Shipments



Exploded view of the rail cask outer and inner vessels.

In 1984, the Department of Energy (DOE) signed a contract with GPU Nuclear Corporation to accept TMI-2 core debris for use in a research and development program aimed at understanding the accident sequence at TMI-2. DOE is taking the responsibility for transporting, storing, and ultimately disposing of the entire core. The first of more than 250 canisters filled with TMI-2 debris is expected to be delivered by GPU Nuclear to DOE in mid-1986; the shipping program is expected to last two to three years.

During the planning stages for handling core debris, EG&G Idaho (a DOE prime contractor at the Idaho National Engineering Laboratory) investigated spent fuel shipping cask options. The requirements for TMI-2 debris transport led to the decision that new casks be designed, certified, and fabricated for this unique project rather than modify and recertify existing casks. EG&G Idaho also evaluated whether canisters should be transported by truck or rail.

While truck-mounted casks could transport one to three fuel canisters each, the use of a rail cask that holds seven canisters has significant advantages. With more canisters in a rail cask than in a truck cask, fewer shipments will be needed. Only 35 to 40 rail shipments will be required, compared with the potential for more than 250 truck shipments.

Fewer shipments reduce the chance for an accident involving the cask during the transportation sequence and thereby reduce the total risk to the public. In addition, fewer shipments mean fewer loading and unloading operations and reduced radiation exposure to workers. For the overall TMI-2 shipping operation, the use of rail casks is projected to be more efficient and less costly than if truck casks were used.

The choice of rail to transport the TMI-2 core debris led to the development of the Nuclear Packaging, Incorporated (NuPac) 125B rail cask. This cask was designed, tested, and fabricated specifically for transporting the TMI-2 spent fuel debris to the INEL. The cask was certified by the Nuclear Regulatory Commission (NRC) in April 1986.

When the cask design was started in late 1984, several unique factors about the condition of the TMI-2 spent fuel had to be considered. Existing spent fuel shipping casks are certified only for transporting assemblies of undamaged spent nuclear fuel. The NuPac 125B rail cask had to be certified to transport spent fuel debris from the TMI-2 accident. Without the cladding that surrounds the spent fuel in an intact assembly, two barriers are needed during transport to comply with NRC regulations.

Under NRC regulations a cask with two barriers is required. Each barrier is a specified containment boundary that must meet stringent requirements for structural strength and demonstrate that an uncontrolled release of the contents will not occur, even after a sequence of accident conditions.

This double containment in the NuPac 125B rail cask is accomplished by use of two separate and strong vessels, one inside the other, each with a thick lid and seals that will be leak tested before each shipment. In addition to the cask inner and outer containment vessels, there are canisters into which the fuel debris will be loaded underwater at TMI. These canisters are another barrier that prevents a release of material during transport. A complete shipping package includes the double containment cask and its canisters, making three levels of protection to ensure the safety of the public.

Leaktight Design

Another unique feature of the NuPac 125B rail cask is the extremely small rate of leakage of radioactive materials that is allowed after a sequence of serious accidents. Each of the two cask containment vessels was designed, built, and tested to a leakrate low enough that the term "leaktight" is applicable, even during and after hypothetical accident conditions.

The leakrate for leaktight is defined as one-tenth of one-millionth of a cubic centimeter of gas per second at a pressure difference of one atmosphere across the containment boundary. This leakrate is equivalent to about three cubic centimeters in a year, or a bubble growing to about the size of a pingpong ball. Only gas could escape...not radioactive particles.

This low leakrate applies for leakage from the inner to the outer containment vessel, as well as from the outer vessel to the environment. The canisters and containment boundaries in the rail cask will ensure that an uncontrolled release of material to the environment will not occur.

Another important design consideration in developing a safe shipping package for the fuel debris was the control of gases that are generated when radioactive materials are in contact with water. The radiation that is emitted splits nearby water molecules into hydrogen and oxygen gases by a process called radiolysis.

These gases must be controlled during transport of wet radioactive materials or a flammable gas mixture could result. The method of control for TMI-2 fuel debris shipments is to use a catalyst that recombines the hydrogen and oxygen gases into water and allows safe transport of the fuel debris.

One other important consideration in the rail cask design was ensuring that the nuclear fuel contents would remain subcritical under all conditions. Subcritical means that the self-sustaining splitting of atoms that occurs in a nuclear reactor cannot occur in the cask.

The rail cask and the fuel debris canister designs ensure subcriticality of the nuclear fuel. This feature—an overriding design consideration—led to the incorporation of criticality control structures into each canister and the inner containment vessel of the cask.

The criticality control materials are positioned and supported to ensure subcriticality of the nuclear fuel by absorbing neutrons needed to achieve a chain reaction. With these neutron absorbers, subcriticality is maintained even after the sequence of accidents is considered.

Inner Containment Vessel

Each cask consists of an inner containment vessel that fits into an outer containment vessel. The inner vessel is fabricated starting with a hub-and-spoke structure made of stainless steel plates that are welded together. This structure is welded to two large forgings at each end. The structure prevents the seven canisters and their supports, which fit into each opening in the structure, from crushing each other in impact accidents.

Each canister fits into a stainless steel tube that forms part of the containment boundary of the inner vessel. Each tube is welded at the bottom to a thick plate that seals the tube closed at this end. The containment boundary is completed with a massive forging to which the tubes are welded and the thick, stainless steel lid that is bolted to the forging.

The 5-inch-thick lid is bolted down with 24 3/4-inch-diameter bolts. Around the edge of the lid are two O-rings that form the bore seals, which are inspected and leak tested before each shipment.

In addition to the stainless steel plates that separate the seven containment tubes, there are one-inch-thick plates welded around the outside that stiffen the inner vessel and form voids between the plates and the outer surface of the containment tubes.

A neutron absorbing material that solidifies like concrete is pumped like grout into these voids. The neutron absorber ensures that the canisters remain subcritical and the strength of the material, together with the plates, protects the containment tubes from damage should an accident occur.

For added safety, another design feature is incorporated inside the inner vessel. Located at the end of the containment tubes are removable energy absorbers that protect the canisters by crushing under accident conditions. Each energy absorber is an aluminum honeycomb material that limits the axial impact forces on the canisters.

The upper energy absorbers are attached to the bottom of shield plugs—short, solid cylinders of stainless steel added for worker radiation protection. After canisters are loaded into the cask, the shield plugs reduce the radiation from the fuel debris to levels that allow workers to replace the inner vessel lid and test the seals.

Outer Containment Vessel

Like the inner containment vessel, the outer containment vessel has many safety features included in the design. The outer vessel is called a composite wall cask because there are three thick layers of metal that form the wall of the cask. Two layers are stainless steel shells, one inside the other, that have a gap of nearly four inches between them. Molten lead is poured into the gap between the shells. The molten lead pour is accomplished after a brick oven is built around the outside of the cask. The entire cask is heated to a temperature hotter than the melting point of lead and the molten lead is added. When the lead cools and solidifies, it becomes an effective shield to reduce radiation levels outside the cask to below acceptable levels. After controlled cooling of the cask, the shielding effectiveness of the lead is checked with a radiation source to ensure there are no voids in the lead.

The larger stainless steel shell is two inches thick, while the shell that fits inside is one-inch-thick stainless steel. Both shells are welded at the bottom to a thick base plate that is carefully machined to the correct dimensions for welding.

Both shells are also welded to a large upper forging of stainless steel that is machined to very precise dimensions where the outer vessel containment seal is formed. The 7.5-inch-thick lid is bolted in place with 32 1.5-inch-diameter bolts. Around the edge of the lid are two O-rings that form the bore seals, which are inspected and leak tested before each shipment.

Attached to the outer shell are thick, short cylinders of stainless steel that are used to lift or hold down the cask during use. These attachments, also known as trunions, are designed and tested to show that they can support more than the weight of the loaded cask.

Another attachment to the outer shell is a structure called the shear block. This attachment absorbs forces during transport that would jolt the cask forward or backward, and protects the trunions from high inertial loads which may be encountered during transport.

Another safety feature of the rail cask is a thermal shield that would help protect the cask in an accident involving fire. The thermal shield consists of a wire wrapped around the outer shell every couple of inches, covered by a thin sheet of stainless steel welded over the wire, leaving an air gap between the thin sheet and the outer shell. This air gap reduces the amount of heat that can flow into the cask body in a fire because air is a poor conductor of heat energy. The thermal shield and the high heat capacity of the cask would keep temperatures low inside the cask if a fire occurred.

One other structural safety feature gives the cask a dumbbell-shape appearance. Large energy absorbers, called overpacks, are attached to each end of the outer shell. Each overpack is made of a thin plate of stainless steel and filled with foam that crushes on impact, absorbing energy and protecting the cask body. The effectiveness of the overpacks was demonstrated by a series of drop tests, done as part of the cask certification process, that showed the safety of this cask design feature. (An article about the drop tests appears in this Update issue.) □

Special Canisters Designed to Hold Spent Fuel Debris

Three different types of canisters are being used to defuel the TMI-2 reactor. Each has the same general external appearance—a stainless steel vessel 14 inches in diameter by 150 inches long. All have features that ensure safety during transport inside the rail cask.

The first type of canister is called a fuel canister and has a removable upper lid. With the lid removed, there is a square opening into which damaged fuel assemblies with a full cross-section can be lowered.

The second type is a knockout canister and is used in a hydraulic vacuum defueling operation. Water and pieces of debris are vacuumed up with a tool and pumped through the inlet of a knockout canister. The pieces of debris settle out of the water as the flow velocity decreases in the relatively larger diameter of the canister. The water, with residual fine pieces of debris, leaves the knockout canister and enters the third type of canister—a filter canister. This canister captures the fine debris on pleated, 0.5-micron stainless steel filters.

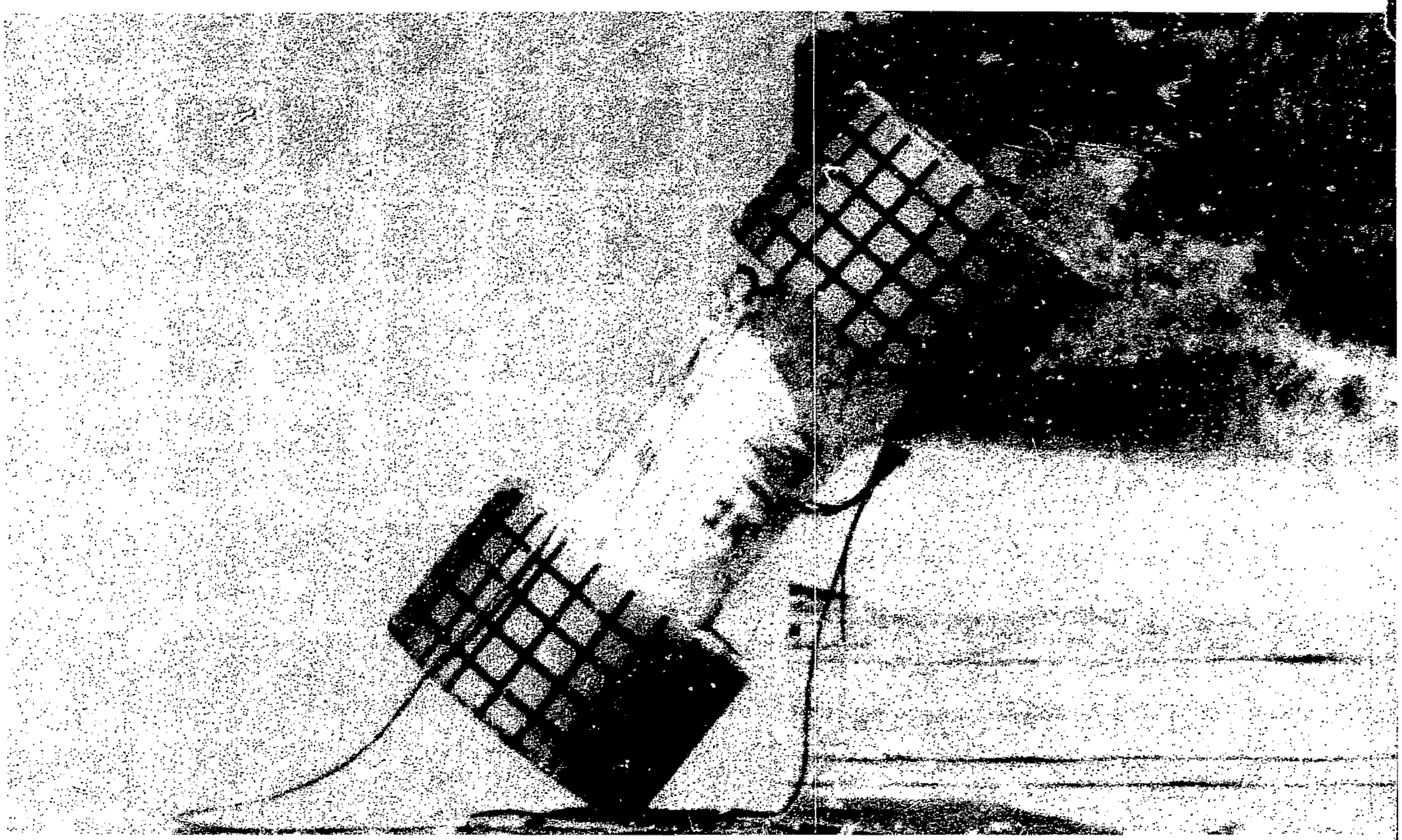
Neutron absorber materials are also built into all three canister types to ensure subcriticality of the nuclear fuel. In the fuel canisters, there is a square of borated aluminum sandwiched between two sheets of stainless steel. To ensure that the square does not move in an accident, lightweight concrete is added to fill the space between the outside of the square and the inside of the canister shell.

The neutron absorbers in the knockout canisters are located inside one large control tube and four small outer tubes. Each tube contains pellets of boron carbide that are seal welded inside. The tubes are supported along their length by thick plates that limit movement of the tubes.

In the filter canisters, the mass of the stainless steel filter media and a central tube of boron carbide pellets (as in the knockout canister) act as the neutron absorbers.

In all three types of canisters, both the upper and lower canister heads have beds of catalytic materials that recombine the radiolytically generated hydrogen and oxygen gases back into water and prevent the formation of combustible gas mixtures. □

Thorough Analyses and Tests Performed for NRC Cask License



Oblique drop at the instant before impact.

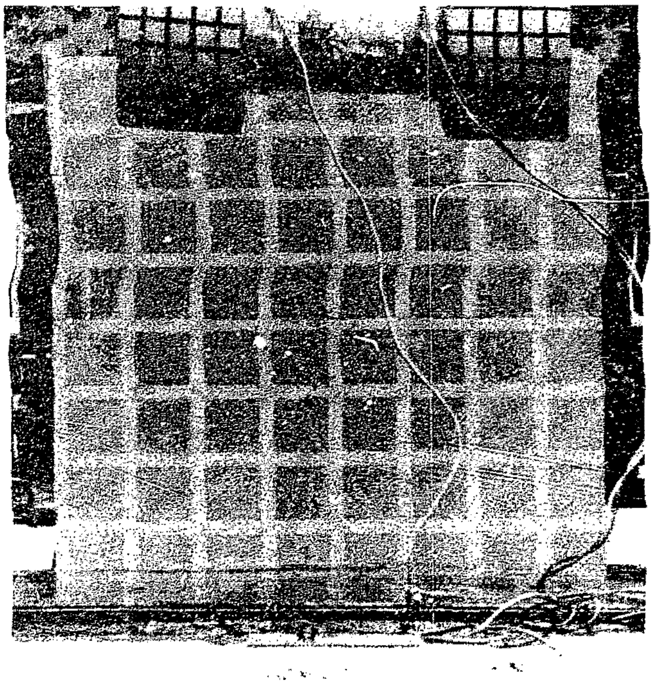
Obtaining certification from the NRC for the NuPac 125B rail cask required thorough analyses of the cask structures, thermal behavior, containment capability, shielding performance, and controls that ensure subcriticality.

The certification for the rail cask is based on an extensive three-volume safety analysis report. The report contains both the results of computer analyses and data from drop tests that were performed to demonstrate the structural integrity of the cask and canisters.

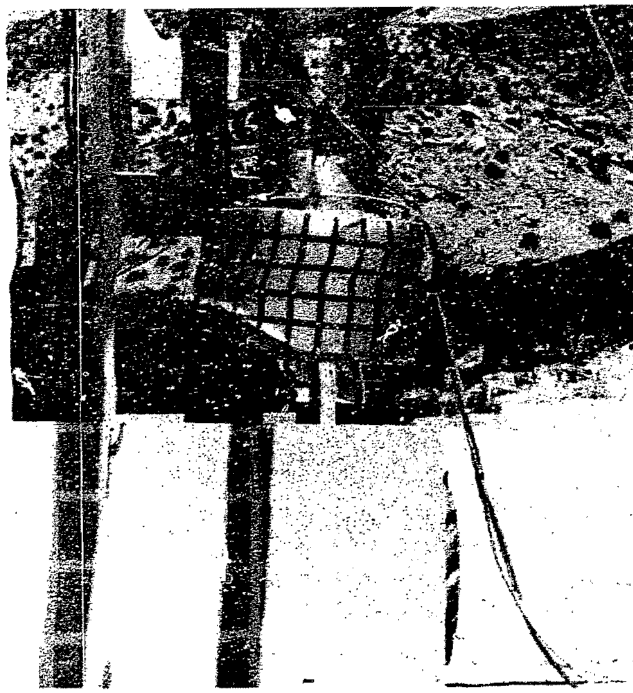
The results of the drop tests confirmed the predictions made in the structural analyses on the strength and behavior of the cask and canister structures during accident conditions. The drop tests provide conclusive evidence of the validity of the analytical models. The test results were given to the NRC to accelerate resolution of potential delays for questions about the amount of conservatism used in the structural analyses.

Cask Tests

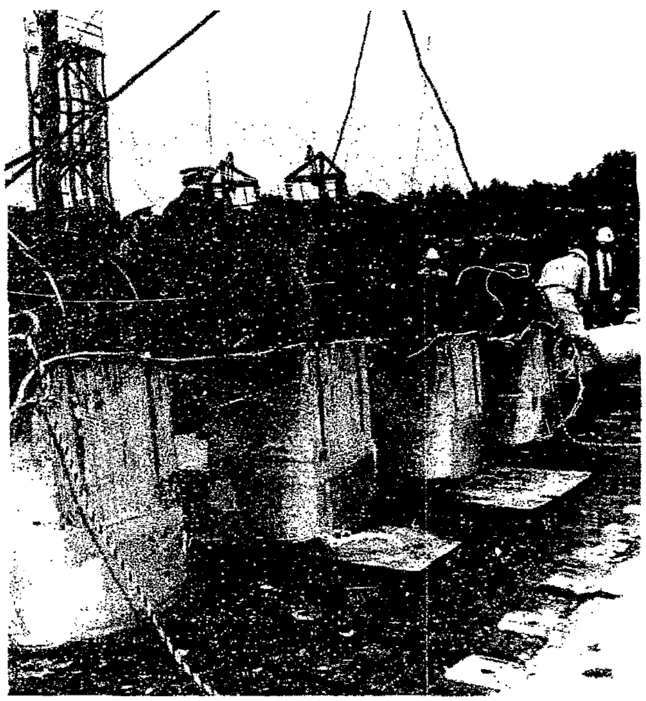
To ensure that only safe packages are used in transport, NRC regulations require that spent fuel shipping casks survive a series of severe accidents, including (in sequence) two drops of the package in an orientation to produce the maximum damage. The first drop is from 30 feet onto an



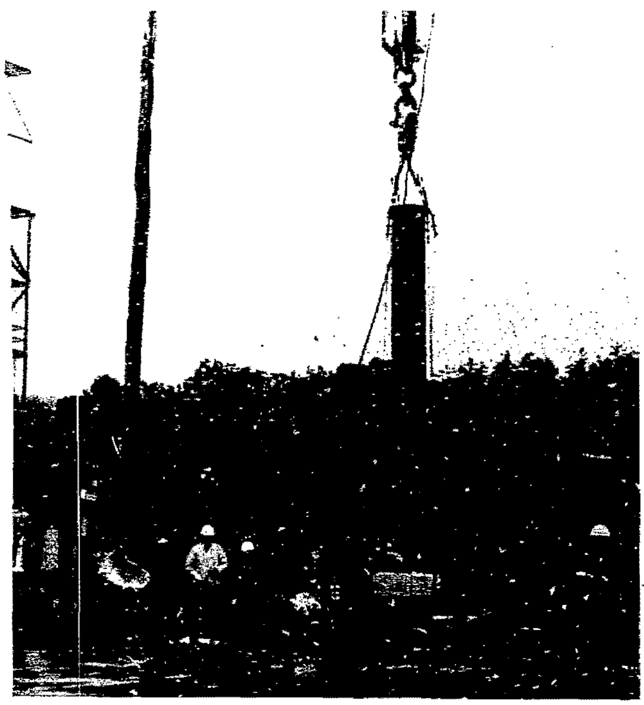
End puncture drop at the instant before impact.



Puncture drop height and orientation check.



Cask simulation vessel with simulation impact limiters for horizontal drops.



Cask simulation vessel and simulation impact limiter for vertical drops.

unyielding surface, followed by a drop from 40 inches onto a steel rod that is long enough to produce maximum damage to the package. The two drops are followed by a 30-minute fire at a temperature of 1475°F, after which the package is assumed to be flooded with water so that controls for subcriticality can be evaluated.

The damage from the 30-foot drop, for both cask and canisters, was first predicted analytically for every possible angle of impact and then demonstrated with a series of drop tests. For the cask drop test program performed at Sandia National Laboratories, a one-quarter-scale model was used. (Scale-model testing is an engineering practice that is used extensively in solving problems in aerospace, civil, mechanical, and nuclear engineering. The scaling laws are widely accepted and provide a cost-effective method of demonstrating design adequacy.) The scale-model tests confirmed the predicted behavior of the full-size cask.

Several drops were made with the quarter-scale model to show, for different cask orientations, the maximum damage to different parts of the cask. Three drops were from 30 feet onto an unyielding surface. Two of the three drops were conducted at a temperature of -20°F to simulate an accident at subfreezing temperatures that might cause brittle materials to fracture upon impact.

The first 30-foot drop was onto the bottom end of the cask to determine how well the cask walls, lids, and closure bolts performed. The test also demonstrated that the energy absorbers within the inner vessel adequately protected the canisters. The oblique angle drop from 30 feet was onto the lid, at an angle that would maximize the stress on the cask body The side drop from 30 feet was done to produce maximum loads on the inner vessel.

The first 40-inch drop onto a puncture rod demonstrated the integrity of the cask side wall in an accident where the outer foam overpacks are not effective in absorbing energy and the cask wall mnst absorb the impact of a protruding object. The second 40-inch drop onto the lid showed how the cask lid would remain undamaged in a puncture accident without reduction of the impact energy by the overpacks.

After the drop tests, the cask was disassembled, inspected, and damage to the overpacks was documented. The model cask was measured, leaktested, and x-rayed to ensure that any structural damage would be found. As expected, the test data confirmed the damage predicted by the analysis for the drop conditions.

The tests showed conclusively the safety of the cask, even in accidents involving severe impacts. For comparison, the impact in a drop from 30 feet onto an unyielding surface is about the same as an impact at 90 miles per hour into two feet of reinforced concrete.

Canister Tests

A series of drop tests with the fuel canisters showed that the square shroud did not move when surrounded by the lightweight concrete in the canister. A full-size knockout canister was subjected to four 30-foot drop tests at Oak Ridge National Laboratory.

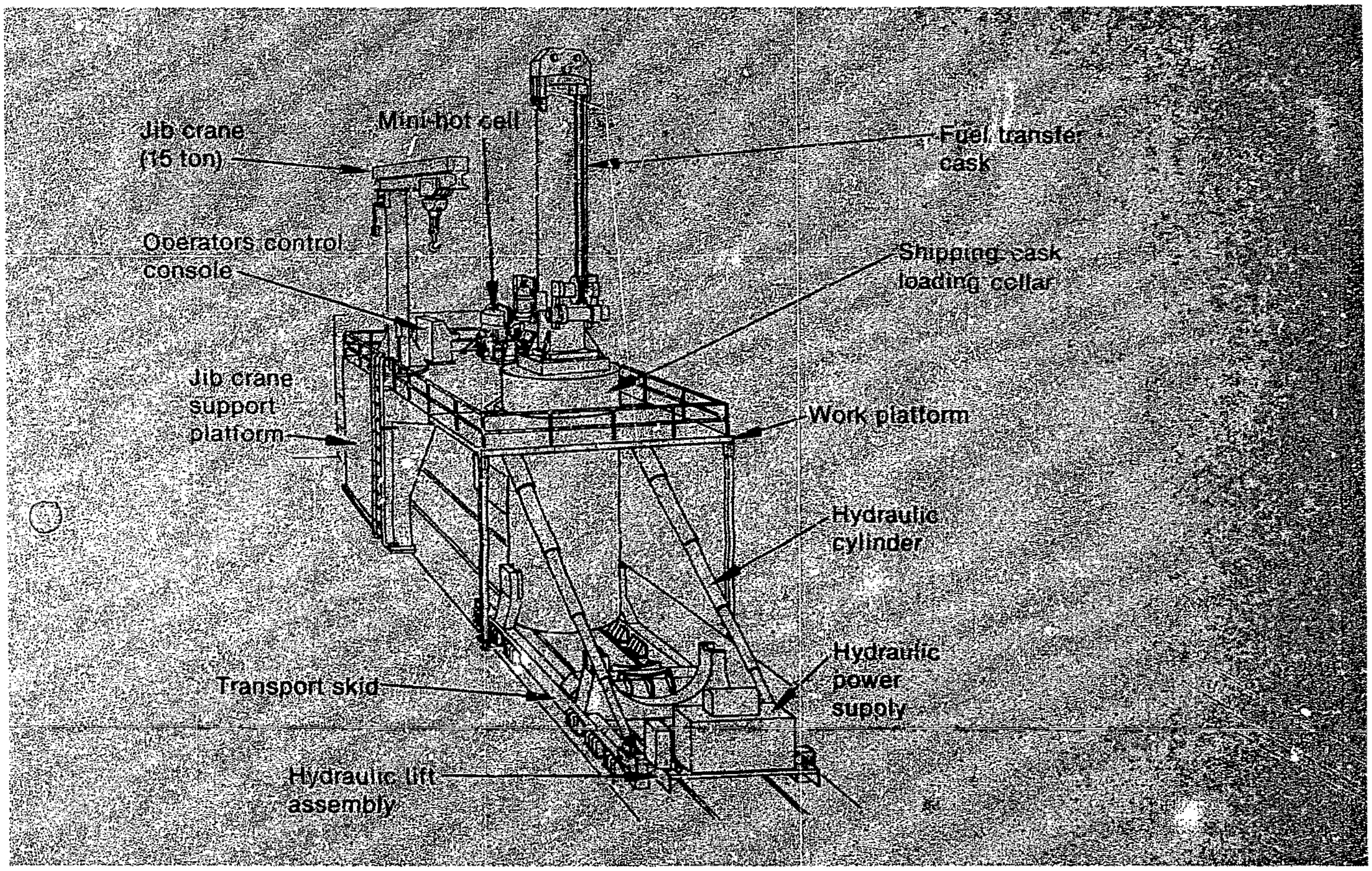
Two of the tests were with the canister in a vertical orientation. One drop test, onto the bottom of the canister, showed that the canister internal structures could safely withstand the force of the fuel debris coming down and compressing the tubes in the structure that contain the neutron absorbers. The second vertical drop was onto the upper end of the canister to show that the weight of the fuel debris could not apply forces that would pull the internal structure apart.

Two other drops were made with the canister horizontal to investigate bending and twisting of the internals. All four tests showed that the tubes containing neutron absorbers experienced no deformations beyond those determined by computer analyses of the structures.

Besides the drop test program, a thorough test program was performed on the catalyst beds installed in each canister to recombine the hydrogen and oxygen gases generated by radiolysis of water. In each test, the performance of the catalyst bed was measured while hydrogen and oxygen gases were added at a flowrate about three times what is expected to be generated in a TMI-2 debris canister.

The testing program helped determine the size and shape of the beds to be built into each canister. The effects of the environments to which the catalyst beds would be exposed, such as chemicals in the water in the TMI-2 reactor, were also investigated. The catalyst test program provided conclusive evidence of the satisfactory performance needed to ensure safe transport of the TMI-2 fuel debris. □

New Loading Procedure Developed for Debris Canisters



TMI fuel cask loading components.

Because the spent fuel storage pools at TMI-2 were being used for accident recovery operations, fuel debris canisters could not be loaded underwater into a shipping cask, which is a traditional industry practice. Instead, the NuPac 125B rail cask is loaded in the TMI-2 truck bay, with the canisters brought to the rail cask in lead-shielded transfer equipment.

The cask loading procedure begins after the overpacks are removed from the cask. The railcar and cask are positioned under a cask unloading station in the truck bay. Screw jacks on the cask unloading station are used to lift the cask and the transport skid from the railcar. The railcar is moved out of the truck bay, the cask and skid lowered to the floor, and the truck bay door closed. The cask unloading station is then moved and stored out of the way.

Two hydraulic cylinders are attached to the cask to raise it from a horizontal lay-down position to a vertical position. The cask is locked in place by attachment to a support tower. A work platform is bolted around the cask and connected to the tower. The cask is opened by removing the lids of the outer and inner containment vessels, and a shielded loading collar is installed. A mini-hot cell is moved over the cask and collar to remove and hold a shield plug from one of the seven tubes in the cask.

A canister is transferred from the spent fuel storage pool by the fuel transfer cask and lowered into the shipping cask. The canister transfer process is repeated six more times. Radiation exposure to workers is controlled by the lead shielding that is built into the mini-hot cell, fuel transfer cask, and loading collar.

After canister loading is finished and the mini-hot cell and loading collar are removed, both the inner and outer vessel lids of the cask are replaced and independently leak-tested to ensure that the cask is assembled correctly. The cask is then lowered to a horizontal position, placed on the railcar, reassembled with overpacks, and inspected and surveyed for radiation levels before being moved to the TMI north gate for transport by the railroad carrier.□

Rail Transportation Program Developed for Cask

In conjunction with the development of the NuPac 125B rail cask and railcar, a transportation program was formulated to ensure the safety of the public while the cask and railcar are in transit to Idaho. The Union Pacific Railroad is the only railroad which serves INEL and was requested by EG&G Idaho to publish a rate for TMI-2 fuel debris traffic from TMI-2 to INEL. The Union Pacific Railroad in turn contacted Conrail, (the railroad that serves the TMI site) as well as other potential connecting carriers serving the northeast United States. EG&G Idaho and DOE are reviewing the potential routes to ensure that they are appropriate in terms of track safety and service requirements.

The railroads being considered are hazardous-material carriers that consistently earn railroad industry recognition for safety of operations and maintenance of track. Evaluation of the routes proposed by the railroads will include various factors such as the highest quality track available, which results in the shortest possible schedule using regularly scheduled railroad service. The routes ultimately selected will be through relatively low populated areas where possible. These requirements will result in a route with connections and tracks that have a low accident frequency index and a minimum number of switching stations.

The casks will ride on new railcars, each with 8 axles and a load capacity of 150 tons. A special design consideration for the rail cars was a safety margin such that the rated capacity of the railcar comfortably exceeded the loaded weight of the cask.

Railroad personnel will maintain continuous contact and use surveillance controls during transport. The railroads have the responsibility for handling any incidents that may occur during shipping and have established emergency procedures and trained personnel to handle hazardous shipments.

In the unlikely event of an accident during shipment, the railroad would take the initial action of isolating the train. Based on the severity of the accident, a nationwide emergency response system could be mobilized if necessary. Because of the safety designs built into the TMI fuel shipping casks, it is highly unlikely that, even in a rail accident, a breach of container integrity would occur.

Should an emergency occur, the DOE has established eight regional offices to provide radiological assistance. Any of these offices can mobilize an emergency response team within two hours; the team can arrive at an accident scene within eight hours. Nationwide, 28 DOE radiological assistance teams are available. The number of personnel responding and type of equipment assigned would depend on the nature of the emergency.

The total shipment time from TMI to Idaho is expected to be less than two weeks. With more than 250 canisters expected to be used and 7 canisters per cask, 35 to 40 shipments are planned. While one cask is being loaded at TMI, another will be being unloaded at the INEL.

Shipments are expected to begin in mid-1986 and should be completed in two to three years. Before actual shipments begin, the designated governor's representative in each state through which the shipments pass will have received a notice of the pending shipping campaign. DOE, which is responsible for shipping the TMI-2 fuel debris, will continuously monitor all aspects of the fuel shipping program.□

Core Debris to be Stored at INEL; Researchers to Have Access

On arrival at the INEL, the rail cask is removed from the railcar and transferred to a truck transporter for the 30-mile trip to the research and storage facility Hot Shop at Test Area North. Inside the Hot Shop, operations for unloading the canisters from the cask are done remotely.

Each canister is withdrawn from the cask, taken to a pool of water, and lowered into a storage module. Each module holds up to six canisters. When a storage module is full, each canister is vented with a specially designed venting and gas sampling system before being filled with demineralized water.

The modules are moved to storage locations in the pool and placed together, but not interconnected. After each module is in place, a gas venting line is connected to each canister. These fuel storage modules were designed to be stable and subcritical under all potential accident conditions.

Storage of the TMI-2 core debris is planned for up to 30 years at INEL, a DOE-owned facility located 50 miles west of Idaho Falls, Idaho. At the INEL, researchers will have access to core debris for the core examination research and development program. Until now, they have had only small samples of the damaged core to examine. While progress in understanding the accident sequence at TMI has been made, scientists at the INEL and at other nuclear research facilities can develop the fullest possible understanding only by studying debris from many core locations. This stored material will offer them that opportunity. □

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ADDRESS CORRECTION REQUESTED

UPDATE

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