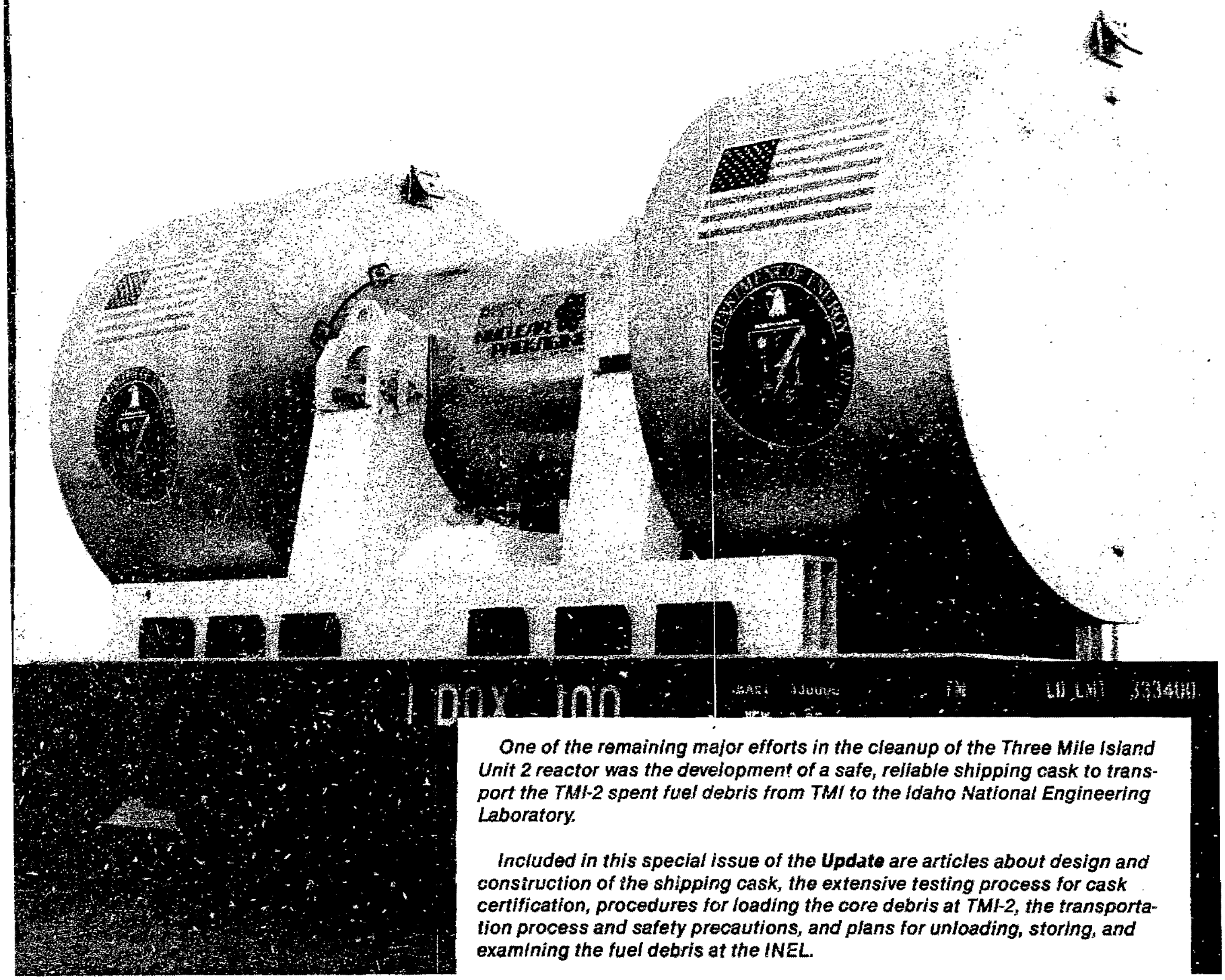
TMI Unit 2 Technical Information & Examination Program

UPDATE

Volume 6, Number 1 April 1986

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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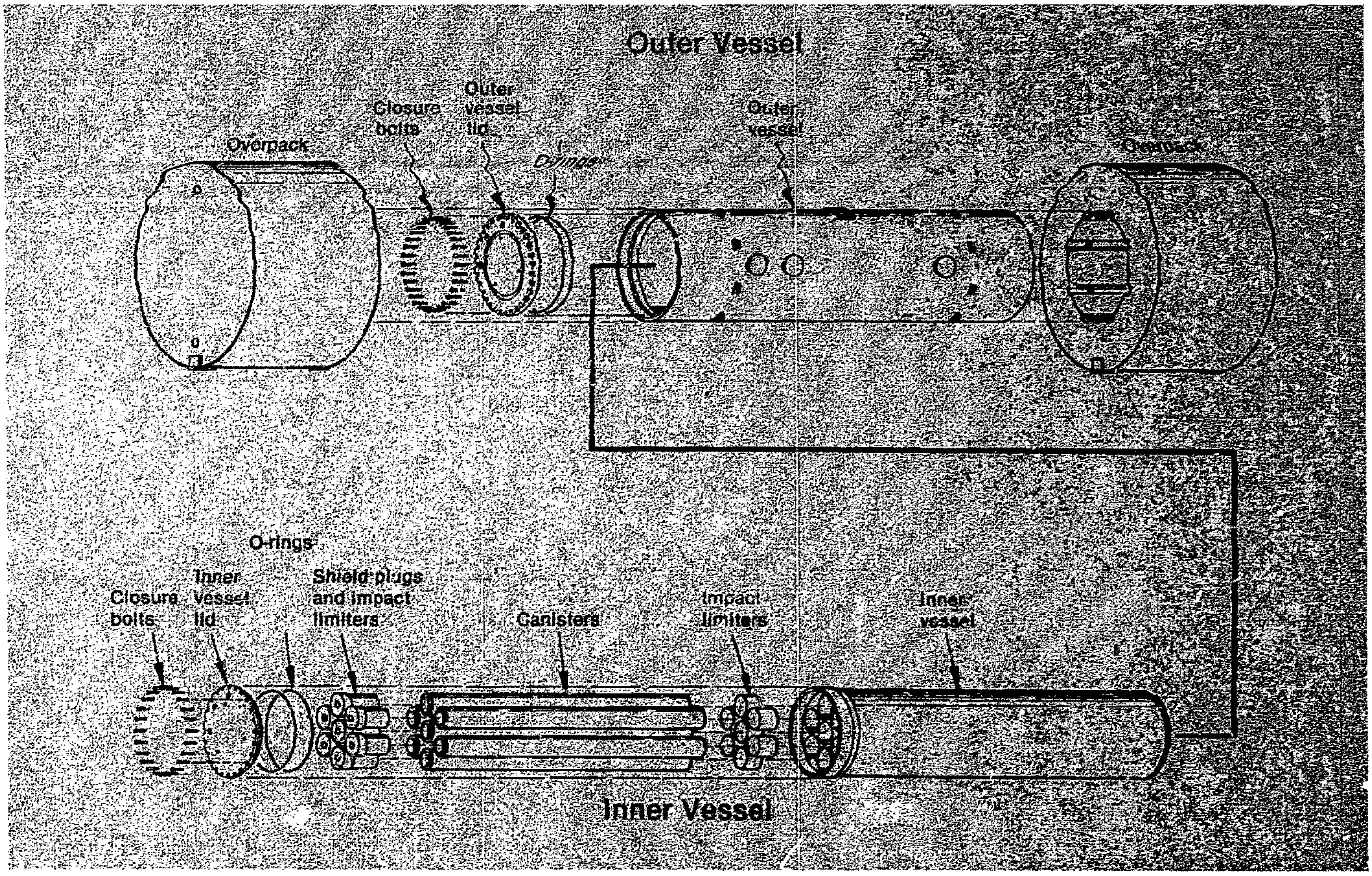
Special Cask Developed for Core Debris Shipments



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 assembles 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.

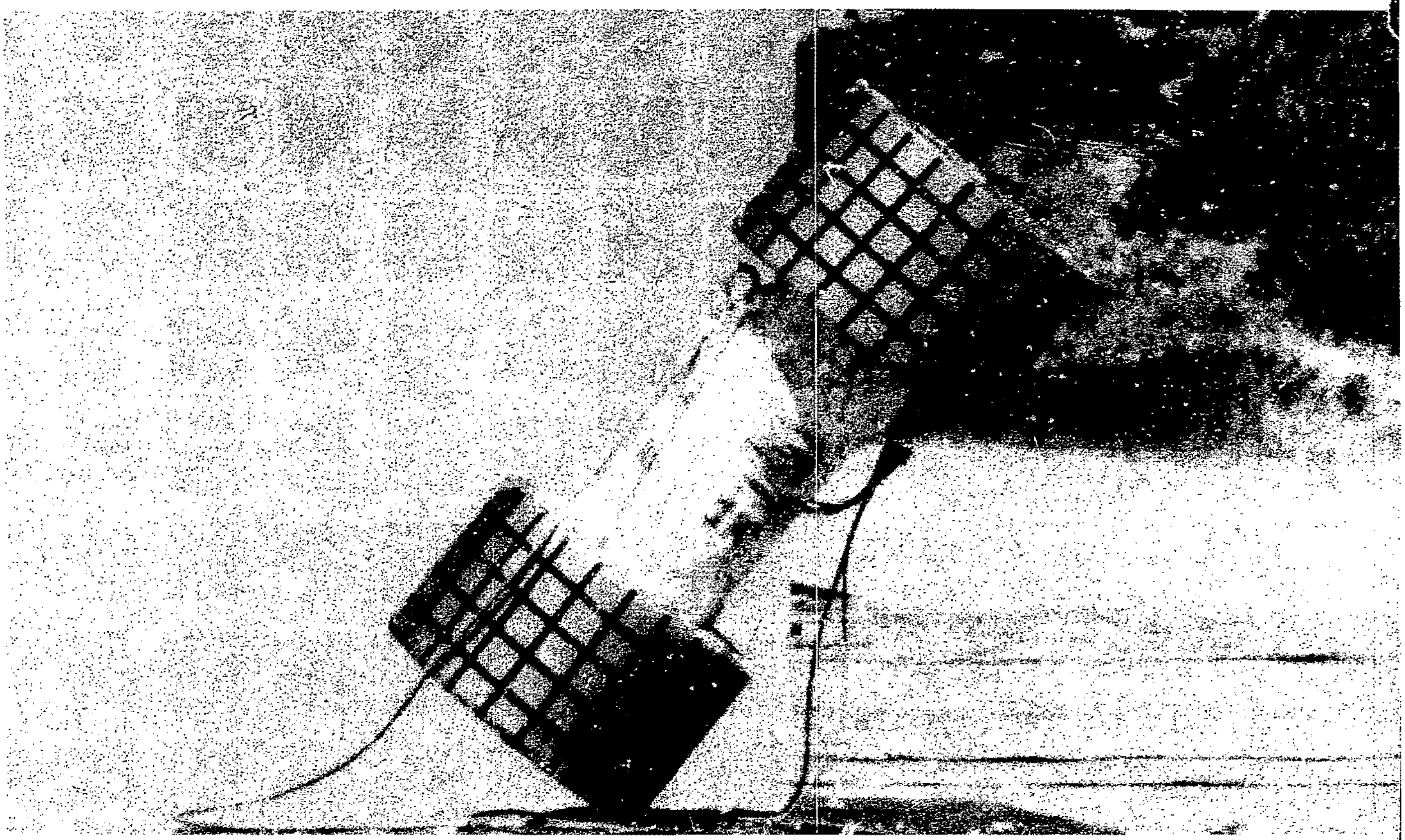
Neutron absorber materials are also built into all three canister types to ensure subcriticality of the nuclear fuel. In the fuel canisters, there is a square of borated aluminum sandwiched between two sheets of stainless steel. To ensure that the square does not move in an accident, lightweight concrete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

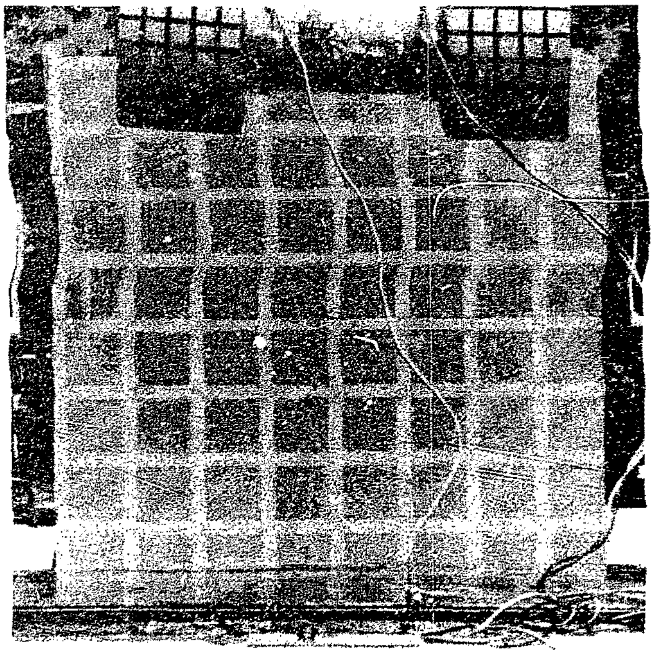
Obtaining certification from the NRC for the NuPac 125B rail cask required thorough analyses of the cask structures, thermal behavior, containment capability, shielding performance, and controls that ensure subcriticality.

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.

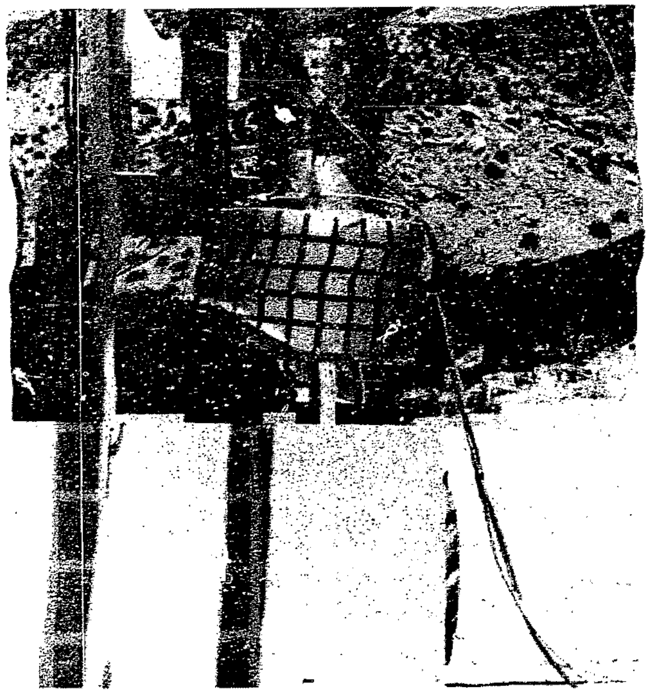
The results of the drop tests confirmed the predictions made in the structural analyses on the strength and behavior of the cask and canister structures during accident conditions. The drop tests provide conclusive evidence of the validity of the analytical models. The test results were given to the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

Cask Tests

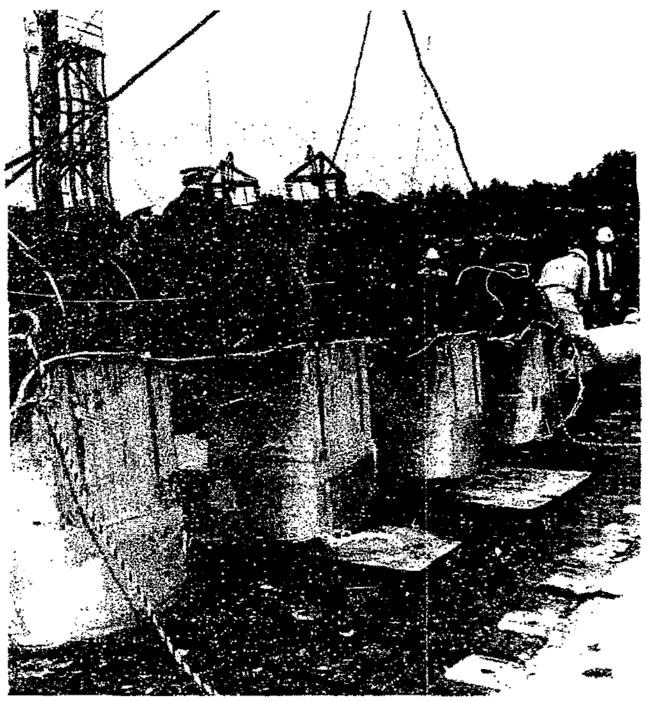
To ensure that only safe packages are used in transport, NRC regulations require that spent fuel shipping casks survive a series of severe accidents, including (in sequence) two drops of the package in an orientation to produce the maximum damage. The first drop is from 30 feet onto an



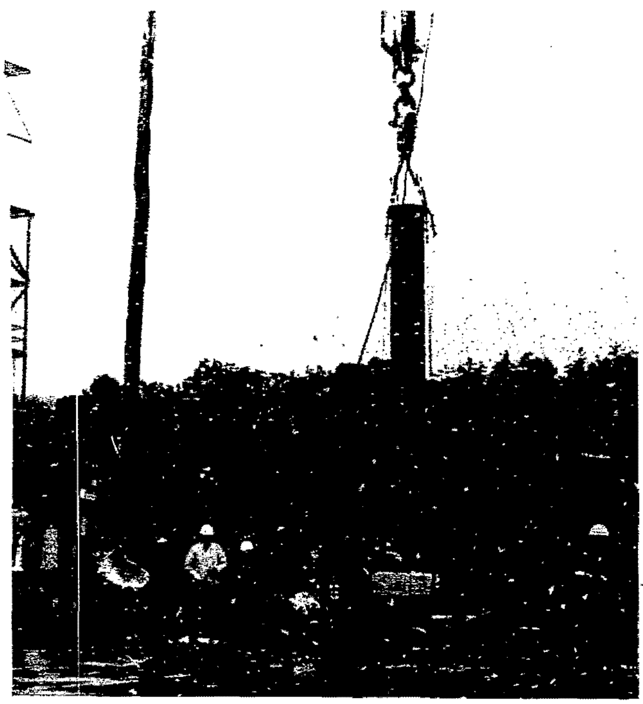
End puncture drop at the instant before impact.



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 must 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.

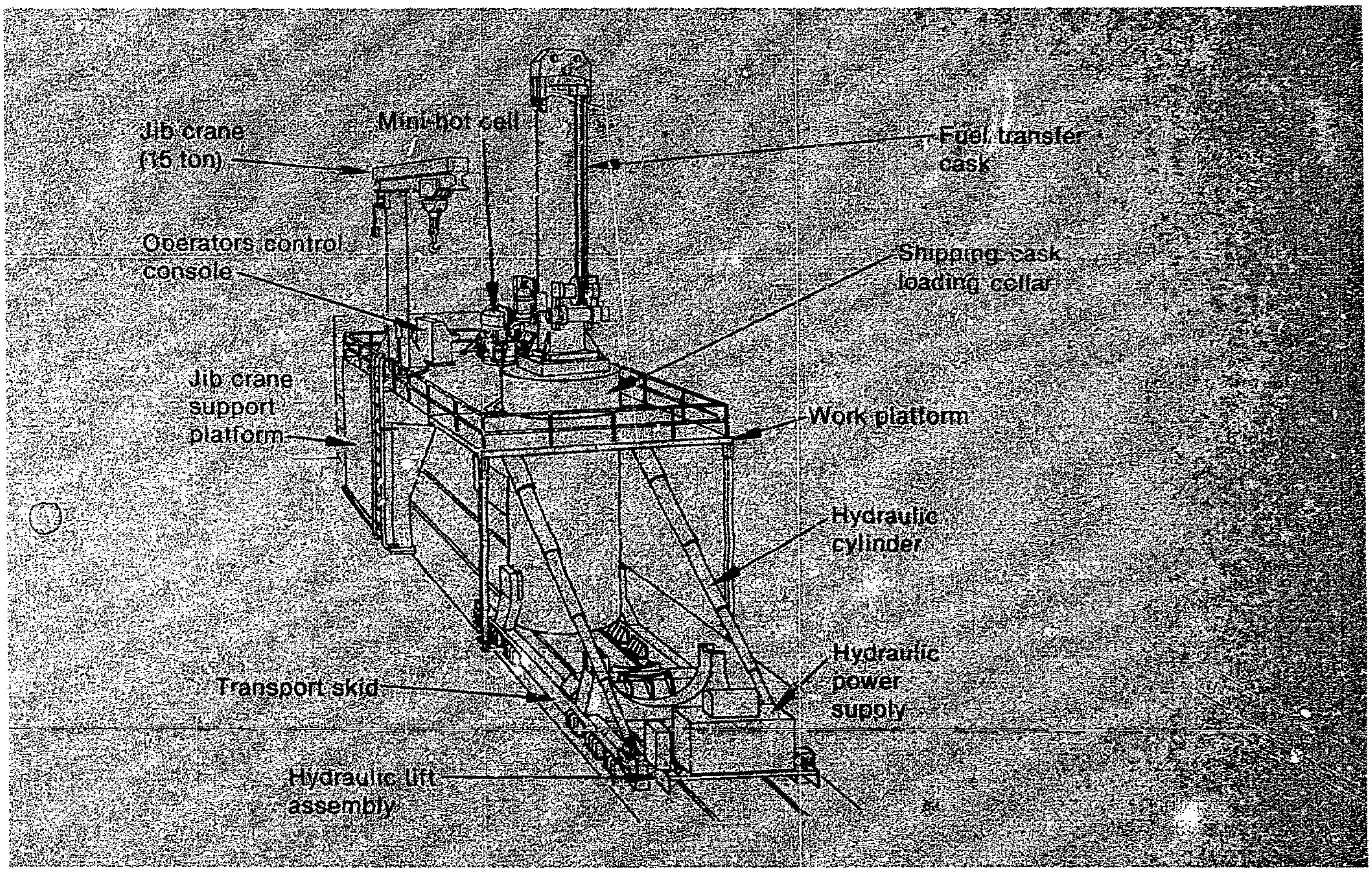
Two of the tests were with the canister in a vertical orientation. One drop test, onto the bottom of the canister, showed that the canister internal structures could safely withstand the force of the fuel debris coming down and compressing the tubes in the structure that contain the neutron absorbers. 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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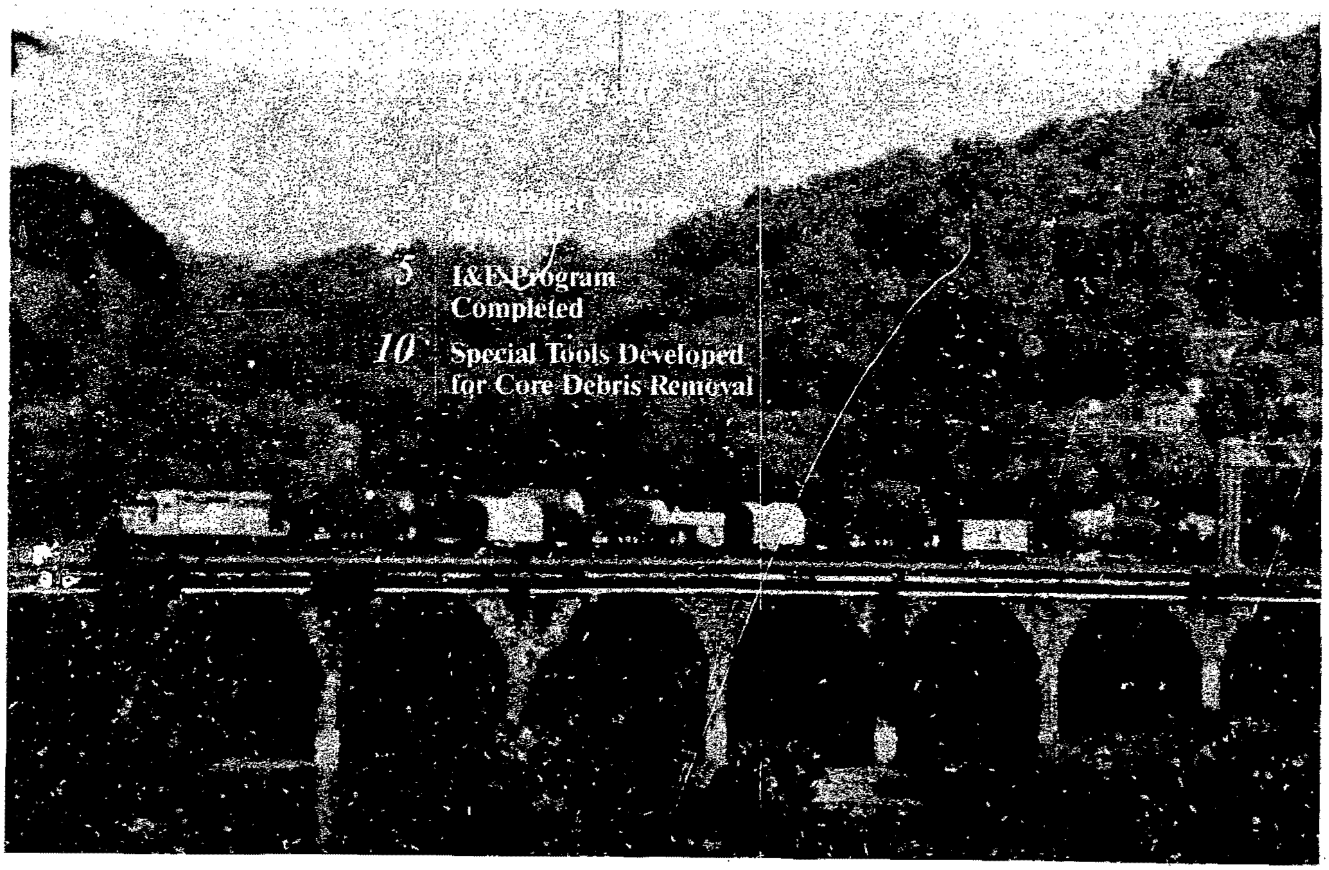

Core Debris *Shipping* Program

Two shipments of TMI-2 core debris have been sent to INEL. The first shipment, with one shipping cask, left TMI on July 20, 1986. The second shipment, with two shipping casks, left TMI on August 31, 1986 and included the core bore samples. Both shipments were uneventful. A third shipment is scheduled for mid-December.

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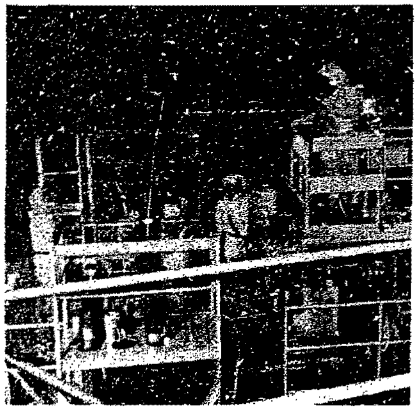
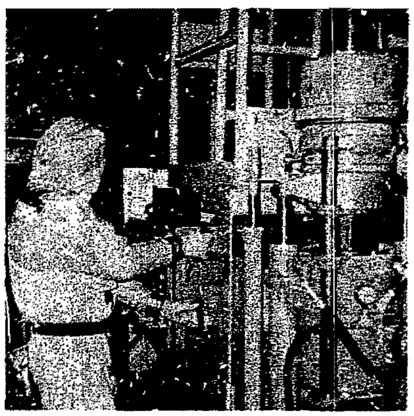
Core Borer Samples Removed



Three-man drilling crews . . . supervised by an EG&G technical advisor . . . operated 16 hours per day . . .



. . . operating the drill rig, monitoring its performance . . .

. . . repositioning equipment, and adding drill casing.

A significant milestone was reached at TMI-2 in July with the removal of stratified core debris samples from the reactor vessel. Once examinations and analyses are complete, the information gained from these core samples is expected to contribute to the resolution of several important research issues.

These issues include improving the definition of current core conditions, advancing the understanding of the accident scenario, and establishing location and distribution of retained fission products. In addition, information developed during core borer operations will significantly aid core debris removal (see box). This information was developed both from drilling data and from video inspections made through the bore holes.

The need for a thorough understanding of conditions inside the damaged reactor was recognized during the early stages of the TMI-2 program. More than simply identifying the end-state condition of the core, understanding the thermal, chemical, and mechanical processes that occurred during the accident was established as a priority concern. The release or retention of fission products by the core is at the center of severe accident predictions and related licensing issues, and was recognized as an important topic for investigation at TMI-2.

Similarly, the events and conditions contributing to the relocation of core materials, as well as the timing of those events, make up the major data points for reconstructing the accident sequence. Vital to all these considerations is the ability to acquire meaningful core samples.

The research community requires physical samples representing the spatial extent of damage or degradation. With analysis, the samples must be capable of providing data to characterize the variations in postaccident core materials present, as well as represent as-built variations in fuel assembly types and locations.

To be meaningful, the samples had to be traceable within the three-dimensional geometry of the core. Similarly, those responsible for defueling plans needed data on the type and distribution of altered core materials, both in the normal core space and in the regions within the lower core support structures. The latter information, to be useful, had to be available shortly after drilling. An overriding consideration was to minimize delays to the plant recovery and defueling operations.

The Core Stratification Sampling (CSS) Project, referred to as the "core borer" project, was developed as a coherent approach to the complex task of in-core sample acquisition. Starting with equipment and technology currently available in the mining/geology industry, the system was extensively modified to meet the special operating and environmental requirements of the TMI-2 Reactor Building.

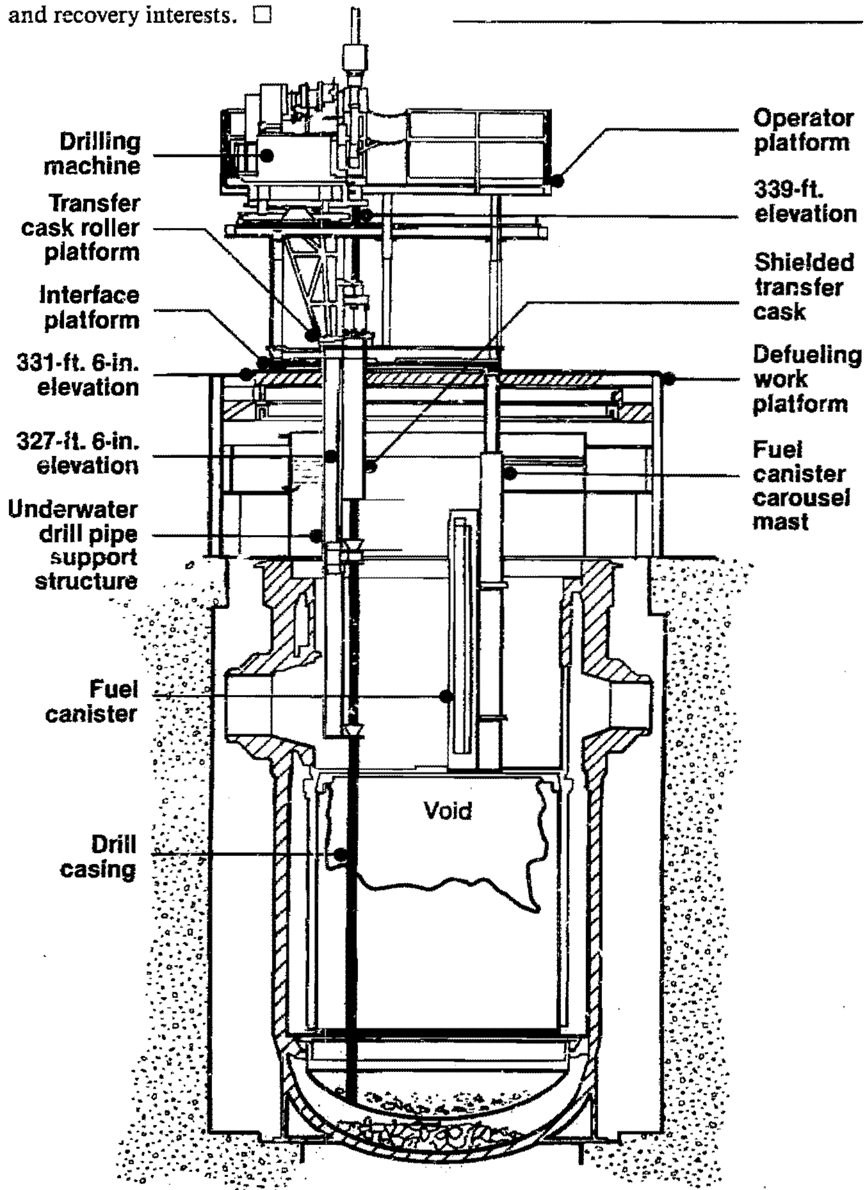
The drill unit was modified to provide precision positioning over the reactor vessel, to incorporate a microprocessor for operational control and safety interlocks, to record drilling parameters (torque, load, etc.), and to provide relevant plant protection functions. For the most part, the sample-cutting hardware was derived directly from the mining industry, with the drill bit the only major departure from standard, off-the-shelf equipment. The bit carried special teeth of diamond-faced tungsten carbide, the only configuration found to tolerate the combination of hard, ceramic-like materials as well as the ductile metallics encountered during the sampling operations.

Ten core samples were removed from the reactor vessel and loaded into five shipping canisters for shipment to the INEL. Once at the INEL, the sample materials were removed from the canisters and prepared for distribution to several laboratories where extensive examinations will begin.

Current examination plans include participation by both foreign and domestic laboratories, including facilities in Japan, Canada, and up to six European countries. The examination and analysis activities are expected to take more than two years to complete.

The unqualified success of the sample acquisition project is the direct result of a strong cooperative effort between GPU Nuclear (GPUN) and EG&G Idaho, Inc., with direct benefits to both the research community and recovery interests. □

Core boring machine for TMI-2 reactor.



Core Bore Findings Support Defueling

Drilling data and video inspections through the bore holes provided significant new information to support defueling operations. Among the findings were:

- The amount of force required to drill through the core indicates the core material, while containing a significant quantity of resolidified material, is not as hard as once thought.
- The normal core region contains loose debris, resolidified material, and apparently intact remnants of fuel assemblies, as expected.
- Damage to reactor components below the core region appears to be less than expected. Some minor damage was found on the eastern side.
- Less debris was found in reactor core-support components than expected.
- Most debris in the bottom of the reactor vessel appears loose enough to be removed with vacuuming equipment.
- During the 1979 accident, the bottom 2 to 3 1/2 feet of the core remained covered with water.

As a result of these findings, defueling planners are reviewing tooling requirements. To date, approximately 25 of the estimated 150 tons of core debris have been removed. □

Instrumentation and Electrical Program Completed

The TMI-2 Instrumentation and Electrical (I&E) Program, begun in 1980, was completed in June 1986. The program was designed to take advantage of the unique opportunity offered by the TMI-2 accident to evaluate a variety of instrumentation and electrical equipment for the effects of exposure to accident conditions including steam, spray, and radiation, as well as hydrogen burn and the resultant overpressure.

The examination of this equipment over a period of several years also provided information on long-term exposure to moisture. Findings of the TMI-2 I&E Program support the general conclusion that the plant instrumentation and electrical components performed well with respect to their required functions under accident conditions.

The TMI-2 I&E Program also identified and analyzed a number of installation problems and instrument response characteristics that led to misleading information and equipment failures. These problems included faulty seals and inadequate drains and vents to protect enclosed equipment against moisture, anomalous responses of radiation monitors, and substantial corrosion of electrical contacts over a period of a few years.

The equipment involved included the radiation monitors from which it has not been possible to determine the true radiation profile within the Reactor Building; pressure transmitters that failed because of moisture intrusion; the loose parts monitors that degraded and then failed due to the sensitivity of the electronics to radiation; various switches and contacts that are continuing to fail due to corrosion; solenoid operators for valves that trapped moisture within the assembly; and various other devices that suffered from moisture intrusion.

In addition to analysis of active equipment, cables and connectors have been carefully analyzed. Some 750 circuits were tested using the newly developed ECCAD system (see box). In addition, cables, or sections of cables, were removed from the Reactor Building for in-depth laboratory analyses.

Major Findings

Two major findings have emerged from the program: (1) more attention must be given to the prevention of moisture intrusion during the design, construction, operation, and maintenance of nuclear power plants, and (2) while basic engineering designs of electronic devices are generally adequate, applications engineering and specifications should be improved. These two findings are closely related.

Moisture Instrusion—The major cause of I&E equipment failure was moisture intrusion, generally caused by inadequate seals on housings, conduits, fittings, and connectors. Where seal integrity was maintained at the cable entry into the equipment housing, the internals were generally not corroded and the device was operable.

For example, seven pressure transmitters were removed from the Reactor Building for evaluation at the INEL. All had been located above flood level in the Reactor Building and were exposed to approximately the same environment. Three of the pressure transmitters were made by manufacturer A and four by manufacturer B. All of the A units survived the accident and postaccident; one of the B units survived the accident and postaccident, and another B unit survived the accident and one year of postaccident before failing.

ECCAD System Description

The Electrical Circuit Characterization and Diagnostic (ECCAD) system, developed under the TMI-2 I&E Program, can make a significant contribution to predictive maintenance for electrical circuits. The ECCAD system is a computer-controlled measurement system designed to characterize electrical circuit parameters that might impact the ability of a circuit to perform its function. For example, if the circuit energizes a motor for a motor-operated valve, the ECCAD system can determine if all connections or contacts are good, if proper voltage can be applied to operate the motor, and if the motor is electrically functional.

The system functions by measuring basic electrical parameters and by sending an electromagnetic pulse through a circuit. By analyzing the reflected pulse and related electrical data, the condition of the circuit can be determined and exact locations of circuit abnormalities can be established. Further, this information is stored in the computer and can be compared with data taken earlier or later to determine if circuit deterioration is taking place.

The ECCAD system is composed of standard electronic test equipment that is readily available on the commercial market. The system is controlled by a Compaq personal computer. The computer:

- Controls individual instruments, setting critical values
- Performs a self-test on the instruments
- Sequences the instruments
- Formats the data, ensuring a standard data set of high quality.

For additional information on ECCAD, refer to *Update*, Vol. 5, No. 3, August 1985, or contact:

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Laboratory analysis showed that all of the failures resulted from moisture intrusion. Those units that survived had either an adequate internal seal (manufacturer A) or a properly installed conduit and junction box (one of manufacturer B's units). A proper installation specification, calling for sealing the unit (as was done by manufacturer A), or for a junction box with breather, drain, and correct conduit entry would have precluded moisture intrusion and extended the life of the equipment.

Other Findings—While moisture intrusion was the major cause of equipment failure, other significant findings were made.

- ***Dome Monitor***

The Reactor Building dome radiation monitor, with shielded ion chambers and electronics, was the only radiation monitor inside the Reactor Building with the capability to measure and indicate LOCA-level radiation. This monitor was the subject of extensive postaccident examination in efforts to understand the monitor response and to determine radiation levels inside the Reactor Building during the accident.

The dome monitor design shows that insufficient consideration had been given the fact that the energy content of the radiation changes with time during the course of an accident. By not requiring a flat gamma energy response under all radiation conditions, radiation measurements were inaccurate. Also, the electronics (specifically the MOS transistors) were significantly degraded by radiation exposure. Specifying and testing the dome monitor design for postaccident radiation dose levels could have led to improved performance of this equipment.

- ***Area Radiation Monitors***

Three radiation monitors were selected for early removal in an attempt to establish an improved knowledge of radiation levels during the accident. All three were located in the Reactor Building and were exposed to the accident and postaccident environment. All three monitors were of the Geiger-Mueller (GM) tube type, with an accompanying electronics package which fed square waves (one for each GM pulse) to an electronics package mounted outside the Reactor Building.

One ARM provided an erroneous (low) indication of the high radiation levels. It was discovered that the area radiation monitor gave on-scale readings when it should have given high, off-scale readings. The device did have a fail-safe circuit that was supposed to ensure high, off-scale readings for high input radiation levels. However, in the presence of the accident radiation (estimated to be between 2.5×10^5 Rads and 1×10^6 Rads), the circuit did not work. Failure to require proof of performance at high radiation levels resulted in misleading information that could have hampered accident mitigation activities.

- ***Loose Parts Monitor Charge Converters***

Charge converters associated with the loose parts monitoring system were found to have failed due to radiation sensitivity of semiconductors. This failure occurred in the first few days of the accident when the system was being monitored very closely to detect loose parts moving through the systems and to assess core damage.

This type of failure would mask or distort real loose parts signals. The studies at TMI-2 led to the determination that similar failures were occurring during normal operating conditions at another operating nuclear plant. This problem was subsequently corrected through redesign by the manufacturer.

The specification of a required radiation operating level and total radiation dose for this equipment could have led to the use of an alternate design or installation at a location with a lower radiation environment.

- ***Solenoid Valves***

  Two Class 1-E solenoid valves were removed from the Reactor Building air cooling and purge system. Both solenoids were operational except that one limit switch failed to respond to the valve position. One valve shell was rusted from moisture that had entered the solenoid housing, due to a flaw in the configuration of the conduit installation. The limit switch failure was moisture related and the lead wire insulation to both valves had embrittled. The long-term integrity of these valves could have been improved by ensuring protection against moisture intrusion as well as by specifying the use of materials that would not prematurely age and embrittle from heat or radiation.

These examples, typical of the equipment problems found during the TMI-2 I&E Program, led to the following general conclusions:

- Moisture intrusion is the major cause of equipment failure and, as such, must be considered in specifications, equipment designs, and installation and maintenance procedures.
- Applications engineering should be performed on a wider range of equipment, not just safety-related equipment. Analysis should include abnormal (e.g., LOCA) operating conditions and should address information needs for accident mitigation activities.
- Qualifications testing should include normal and abnormal radiation environments when it is vital that equipment continue to operate in such adverse environments.
- Predictive maintenance should be encouraged to avoid unnecessary interruption of electrical circuits for maintenance purposes. NRC studies show that 35% of electrical failures are maintenance-induced. The use of diagnostic or trending systems (such as an ECCAD system) would allow maintenance to be performed only where needed.

Further information on the TMI-2 I&E Program is available in the following reports. Copies of these reports are available from:

TMI-2 Technical Information and Examination Program
P. O. Box 88
Middletown, PA 17057

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R. D. Meininger, et al., *TMI-2 Cable/Connections Program FY-85 Status Report*, GEND-INF-068, September 1985.

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Special Tools Developed for Core Debris Removal

A number of special tools have been developed to meet the unique challenge of removing TMI-2 core debris. They are being used inside the reactor vessel, underwater, in a radioactive environment, and are operated from up to 35 feet away.

The current tooling inventory represents the culmination of several years of intensive technical planning. The overall philosophy calls for the simplest, least-developmental tools and techniques. Tooling is permitted to become more complex and developmental only as dictated by proof-of-principle testing, operational experience, and increasing knowledge of core conditions.

In late 1982, GPUN and their subcontractors, with funding support from DOE/EG&G Idaho, Inc., started the reactor vessel defueling tooling development effort. The thrust of this effort was to provide a tooling system capable of removing approximately 100 tons of uranium dioxide fuel and 50 tons of core components from the TMI-2 reactor vessel. The initial fuel and core debris removal tooling was delivered to TMI in time for the first phase of reactor vessel defueling, starting in October 1985. (Reactor vessel defueling operations are expected to be completed by December 1987). This tooling, and the defueling tooling that will follow, provides the means to prepare the reactor vessel core material and to place it in specially designed debris canisters. These canisters will be placed in temporary storage at the Idaho National Engineering Laboratory, with DOE having responsibility for their ultimate disposal. (See item on shipping program on page 1 of this issue of *Update.*)

Table 1. **Defueling activity and related tooling.**

Defueling Activity	Tooling
Core debris sizing and reactor internals disassembly	Shears, shredder, impact chisel, cutting station, abrasive saw, brushes, abrasive water jet, cavitating water jet, plasma arc torch, incore instrument cutter, core boring machine, and cutoff saw.
"Pick and place"	Top access partial fuel assembly removal tool, scoops, hooks, tongs, grippers, tampers, sweepers, debris container handling tools, cranes, and handling bridges.
Fines/debris vacuuming	An integral fines/debris vacuuming system with specialized capturing canisters and an assortment of vacuum nozzles.
Tooling support equipment	Work platforms and support structures, control systems, cable management system, closed-circuit television viewing and lighting system, robotic arm manipulator, tooling positioners and stabilizers, debris canisters and buckets, and canister positioning system.

Tooling requirements are based on four phases of reactor vessel defueling as follows:

- Initial defueling—removal of fuel element end fittings and other loose debris, including vacuumable fines, from the rubble bed.
- Core region defueling—removal of debris remaining after the completion of initial defueling in the core region. This phase is differentiated from initial defueling in that significant debris sizing operations will be performed. It is also intended that the removal of the once-molten, "hard crust" will be accomplished during this phase.
- Lower head defueling—removal of debris from the lower reactor vessel head. The lower head includes the volume directly below the flow distributor.
- Core support assembly (CSA) defueling—removal of debris from the core support assembly. The CSA consists of bolted, stainless steel subassemblies including the core support shield, core barrel, thermal shield, lower grid, incore instrument guide tubes, and flow distributor.

In addition to uranium dioxide fuel, the core material consists of fuel rods, end fittings, control rod material, spacer grids, fuel cladding, instrument strings, control rod spiders, and neutron poison materials.

All the defueling tooling is designed for remote operation, underwater in the reactor vessel, and is controlled at or near the main work platform located over the reactor vessel. While several tools are hoist mounted and manually operated, most of the tooling is hydraulically operated. The tool "end effectors," which represent the mechanical devices performing the work, are designed for mounting on poles and tool positioners up to 35 feet long. The accompanying table lists the tools.

The main work platform, on which most of the defueling tooling is staged and operated, is located above the reactor vessel flange. The work platform is shielded and can be rotated. It is equipped with ports and slots covered with removable hatches. These openings permit workers to use defueling tooling and support equipment inside the reactor vessel, while minimizing radiation exposure.

Before being placed into service, the tooling and support equipment are functionally tested to ensure that they will interface as designed and perform as intended. Functional testing is normally performed at the manufacturer's facility or on-island at the defueling test assembly reactor vessel mockup. GPUN is currently reviewing plans for the design, fabrication, and testing of CSA and lower head cutting tools and equipment. This tooling will complete the reactor vessel defueling tooling requirements. Recent reactor vessel core boring and associated video inspection results suggest that there is no reactor vessel core condition that the present and anticipated defueling tooling and support equipment inventory cannot accommodate.

During the past few years, robots have played an important role in the TMI-2 cleanup program, helping to reduce worker radiation exposure. To date, five different devices have been used to test or probe in high-radiation areas of the plant. Thus far, no remote-controlled device has been used inside the reactor vessel. As indicated in the table, a robotic arm has been purchased and is expected to be used in the vessel as a light-duty defueling operations manipulator.

The final development of this tooling will complete a major milestone leading to ultimate disposition of the TMI-2 plant. □

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