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March 1, 1988

Dr. Joseph C. Walters, Ph.D.
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27 Palomino Road
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SCRIPT FOR VIDEO ENTITLED "THE TMI STORY: A DOCUMENTARY" - HWR-9-88

Dear Dr. Walters:

Attached is a copy of the script written for the video entitled "The TMI Story: A Documentary" being prepared by the TMI-2 Programs of EG&G Idaho, Inc. for the U.S. Department of Energy. The script reflects comments and refinements offered by several organizations, including the Department of Energy and GPU Nuclear. Presumably, this is a finished script; however, if the Department of Energy provides additional comments between now and March 14, EG&G Idaho, Inc. will edit the script accordingly.

Please study the manuscript and be prepared to verbalize it when you visit this office during the week of 13 March. At that time, both the audio and draft illustrative portions of the video will be constructed. Also, the animation sequences being developed by EG&G Idaho, Inc. or supplied by the Electric Power Research Institute of Palo Alto (CA) will be reviewed and fitted to the script.

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The TMI-2 Programs of EG&G Idaho, Inc. is looking forward to your visit and believes that your involvement in preparation of the video will enhance the quality of product being made for the Department of Energy. In the meantime, if you have any questions regarding the script or video, please do not hesitate telephoning me personally at 208-526-1150.

Very truly yours,

Harley W. Reno, Ph.D.
Principal Program Specialist

bmr

Attachment:
As Stated

Rev. 6
3/1/8

THE TMI STORY: A DOCUMENTARY

by

Harley W. Reno

On March 28, 1979, attention of the nation and world was captured by events unfolding at the Three Mile Island Nuclear Power Station near Harrisburg, Pennsylvania. Early that morning, the Unit-2 reactor ceased operating properly, being shutdown by a series of automated protection systems. Although all systems stopped safely, a combination of equipment malfunctions and human errors eventually resulted in irreparable damage to the reactor. That contributed to involvement of the U.S. Department of Energy and others in research and cleanup operations, and expenditure of private and public funds from several sources totalling more than a billion dollars. This documentary summarizes important contributions by DOE during that period, and it illustrates some benefits industry and the nation gained from both the incident at Three Mile Island and subsequent actions.

The incident at Three Mile Island, or TMI, is divided into three parts, namely the accident, which lasted about 15 hours; forced cooling of the system, which lasted about 30 days; and cleanup of facilities and research, which is taking about ten years.

Before discussing the accident, a brief explanation of normal reactor operations is needed. A water reactor like the Unit-2 reactor of TMI is nothing more than a big hot water heater, which uses nuclear fuel to heat large volumes of water. Water leaves the reactor at about 600 degrees Fahrenheit and is pumped to one or more steam generators, where the heat energy is transferred to a second stream of water. Water leaves the steam generator and returns to the reactor at about 550 degrees Fahrenheit for reheating. Pressure in the primary or reactor system is kept high - approximately 2200 pounds per square inch - to prevent boiling the water.

In the steam generators, water in the secondary system flows in the opposite direction of water from the reactor. Cool water in the secondary system enters the steam generator through the bottom and passes upward around metal tubes,.

containing water from the reactor. The heat moves from the hot water in the primary system to the cool water in the secondary system causing the water in the secondary system to boil and change into steam. The steam spins a turbine, producing electricity for public consumption. The steam continues flowing to a condenser, where it is cooled and converted to water. The water, then, is pumped back to the steam generator, where the steam cycle is repeated.

The process of transferring heat from the reactor to the steam generators to the condenser is the mechanism by which the nuclear fuel, or core, is cooled. Thus, water circulating through the reactor is referred to as "coolant." When a reactor is not operating, coolant must be circulated through the core to remove heat generated by the decay of radioactive products produced during normal operations. Water in the reactor system is maintained at a constant pressure by the pressurizer connected to the pipe transporting hot water from the reactor to the steam generator. Because pressures in the reactor system tend to fluctuate, the pressurizer automatically compensates for slight changes by heating the water or cooling the steam bubble within the pressurizer.

At the beginning of the accident at TMI, automatic protection features in the reactor system operated as designed, safely shutting-down the steam turbines and reactor. But a valve at the top of the pressurizer stuck open, permitting water in the reactor system to escape into the Containment Building. A sump pump in the basement of the Containment Building was activated automatically and began pumping the water into the adjacent Auxiliary and Fuel Handling Building.

When the pressurizer valve stuck open, the steam bubble in the pressurizer was lost, giving an indication that the reactor was full of coolant. Operators in the control room of Unit-2 became concerned about potential overpressurizing the reactor system. There was concern too about the loss of water in the steam generators, loss of water in the pumps returning water from the steam generators to the reactor, and increasing levels of radioactivity in the atmospheres of the Containment, and Auxiliary and Fuel Handling buildings. Apparently, the high pressure injection system, which pumps water into the reactor system during an emergency, was delivering some coolant to the reactor and steam generators. The net result, however, was more coolant escaping from the reactor into the Containment Building than was being added by the high pressure injection system.

At 6:00 AM, two hours into the accident, second shift personnel began arriving according to routine work schedules. The second shift supervisor soon recognized the trouble and ordered operators to close the block valve atop the pressurizer. Further loss of coolant was halted. However, the amount of coolant remaining in the reactor only partially covered the core. As a result, both temperatures in the core and pressures in the cooling system began increasing as water flashed into steam. That effectively prevented the high pressure injection system from replacing coolant lost to the Containment Building or transformed into steam.

As temperatures in the core rose, exposed core materials and steam interacted causing severe damage to structures and fuel assemblies. Some components melted and flowed to lower portion of the core. A "bubble" of hydrogen gas accumulated in the top of the reactor. The hydrogen gas was formed when the steam interacted with hot metals of the exposed core in ways that stripped oxygen

During the last ten hours of the accident, operators opened and closed valves and systems in ways that eliminated the steam voids, reduced the hydrogen bubble in the reactor system, and cooled the core. The operators briefly opened the block valve on the pressurizer and activated the high pressure injection system. The procedure vented steam and hydrogen into the Containment Building and progressively permitted refilling the reactor system with coolant. Temperatures in the core began to decrease. Heat was removed by restoration of forced circulation of coolant through the reactor and steam generators.

Shortly after initiation of venting, hydrogen released into the Containment Building apparently ignited. A rapid increase-decrease in atmospheric pressure of the Containment Building was detected by instruments in the control room. Later examination of charred equipment and distorted doors showed the hydrogen gas had burned and indeed was the source of the change in pressure.

Once voids in the coolant system were filled, circulation pumps in the cooling system were restarted. Temperatures of water returning to the reactor were lower than water leaving the reactor, indicating that flow through the reactor system had been restored. That signaled an end to the accident. However, the basement of the Containment Building was flooded by approximately 600,000 gallons of radioactive water. The atmosphere of that building contained large amounts of radioactive krypton gas. The Auxiliary and Fuel Handling Building was contaminated by approximately 550,000 gallons of water and some gas from the Containment Building.

At approximately 7:00 PM - 15 hours after the Unit-2 reactor began automatic shutdown - the accident was over. Thus, the end of the accident marked the beginning of the final cooling of the core, and the laborious, time consuming, and expensive tasks of cleaning up the facility. It also marked the beginning of a comprehensive research and development by the Department of Energy.

The small bubble of hydrogen gas remaining inside the reactor was removed by venting into the Containment Building. However, to avoid igniting the hydrogen, air in the Containment Building was circulated through a device containing catalytic recombiners, which controlled the concentrations of hydrogen by chemical recombination with atmospheric oxygen to form water vapor.

After the hydrogen gas was forced from the reactor coolant system, circulation of coolant through the reactor system was restored fully. A pump continued circulating coolant for about a month, until temperatures in the system fell below those added to the system by the pumping process. At that point, the pump was turned off and natural convection was allowed to cool the system. Fifteen months after the accident, the radioactive gas in the atmosphere of the Containment Building was vented to the outside during a four week period from June and July 1980. The venting was a carefully controlled process conducted according to a plan developed by Metropolitan-Edison Corporation - operator of the Three Mile Island Nuclear Power Station - and approved by the U.S. Nuclear Regulatory Commission. Metropolitan-Edison Corporation at TMI was reorganized later as General Public Utility Nuclear Corporation and thence into GPU Nuclear Corporation.

From the beginning of the accident, the Department of Energy played an important role at TMI. Initially, DOE's presence there was to support the U. S. Nuclear Regulatory Commission and Metropolitan-Edison Corporation as they labored to control the incident. That was accomplished by making available experts in reactor behavior and experimental facilities at national laboratories. Simulators at the Idaho National Engineering Laboratory were used in recreating various aspects of the accident and testing hypothesized methods for controlling the accident.

In December 1979, President Jimmy Carter charged DOE with the responsibility of implementing the federal portion of the research and development program outlined by the President's Commission on the Accident at Three Mile Island. The commission recognized that the incident at TMI afforded the government and nuclear industry a unique opportunity in understanding reactor behavior during and after a severe core damage accident. The commission believed Unit-2 would provide information not available from severe accident tests conducted at national laboratories. Consequently, the General

Public Utility Nuclear Corporation, the Electrical Power Research Institute, the Nuclear Regulatory Commission, and the Department of Energy, collectively identified by the acronym GEND, signed a Coordination Agreement in March 1980, establishing the Technical Information and Examination Program. The Coordination Agreement outlined objectives of that program and broadly defined methods for achieving those objectives consistent with other obligations of each signatory to the agreement.

An important aspect of that agreement was establishment of a physical presence at TMI by DOE, beginning in 1980. The Technical Integration Office of DOE was supported by $48 million and staffed mainly by personnel from EG&G Idaho, Inc., operating contractor of the Idaho National Engineering Laboratory. The Technical Integration Office was responsible for coordinating activities between GPU Nuclear, other signatories to the Agreement, and special advisory committees established to assist in planning cleanup operations and gathering research materials needed for understanding and explaining the accident. That office assisted in planning and scheduling activities at TMI and at federal installations around the country. It also disseminated technical and scientific information to governments and nuclear industries around the world.

Meanwhile, NRC was preparing a Programmatic Environmental Impact Statement on decontaminating Unit-2 and disposing of wastes. The Environmental Impact Statement, first issued as a draft in August 1980 and in final form the following March, alluded to special capabilities in DOE which could benefit cleanup and waste disposal efforts at TMI. In March 1981, the Secretary of Energy sent a memorandum to President Ronald Reagan, requesting the budget for DOE at TMI be enhanced to accommodate the larger scopes of work suggested by NRC. The President responded positively and authorized a budget expansion. The amount added was $75 million, increasing the DOE commitment by fiscal year 1982 to $123 million.

Following issuance of the Final Programmatic Environmental Impact Statement on TMI, NRC and DOE signed an interagency Memorandum of

Understanding, which specified interagency procedures, roles, and responsibilities for removal and disposition of wastes produced during cleanup of Unit-2. That memorandum, along with the Coordination Agreement, defined how DOE and GPU Nuclear would interact in removing, transporting, and storing or disposing of wastes produced during cleanup. The DOE budget at TMI was increased another $36 million, bringing the commitment to $159 million, beginning fiscal year 1983.

In 1982, DOE assisted GPU Nuclear in initial examinations of the damaged core. Two leadscrews in the control rod system were removed. A miniature television camera was lowered into the core region of the reactor through one of the openings left by a leadscrew. The television camera revealed a large cavity in the core. There was considerable rubble and damaged fuel assemblies at the bottom of the cavity. Portions of damage fuel assemblies were observed around the periphery of the cavity.

In 1983, DOE and GPU Nuclear developed sampling devices which were lowered through the leadscrew openings and used to collect samples of the .

debris. Information gathered from studying the leadscrews, examining videos of the cavity in the core, and analyzing samples of debris collected from the core justified expanding the TMI budget to include formulating an explanation of what happened to the core during the accident. The additional funding was $30 million, bringing the total commitment to TMI by DOE to $189 million. Of that amount, 40 percent was devoted to cleanup of Unit-2 and 60 percent to research and development activities at various federal laboratories.

In March 1984, DOE and GPU Nuclear contractually agreed that DOE would transport, store, and eventually dispose of the damaged core from Unit-2. They also agreed that DOE would transport, store, and prepare for disposal abnormal wastes generated during cleanup. Abnormal wastes are wastes whose characteristics are different from radioactive wastes routinely produced by commercial, nuclear power facilities.

The amount committed by DOE to cleanup of Unit-2 and researching and understanding progression of the accident was less than 18 percent of the costs of cleanup and research. That is, the estimated $1.1 billion was variously shared by other parties: the insurance companies paid $305 million; the customers of GPU Nuclear paid $246 million; the domestic nuclear industry contributed $153 million; the General Public Utilities Corporation paid $82 million; the Commonwealth of Pennsylvania and State of New Jersey contributed $30 million and $11 million, respectively; the Babcock and Wilcox Corporation paid $21 million a after lawsuit - it designed and built the Unit-2 reactor; the nuclear industry of Japan contributed $18 million; and, of course, the Department of Energy spent $189 million, of which $79 million was directly applicable to cleanup of Unit-2. That left an unfunded shortfall of about $38 million. GPU Nuclear estimated that cleanup alone cost $965 million.

NRC, in its environmental impact statement, indicated that cleanup of Unit-2 could be accomplished using existing technology and hardware already available to the nuclear industry and federal government. NRC also noted that cleanup would take from five to nine years to complete. Although that forecast initially seemed pessimistic, in reality it was quite .

realistic. After the accident, NRC, GPU Nuclear, and other organizations at TMI realized that access to the damaged reactor would occur only after peripheral facilities were decontaminated.

More than one year passed before the Auxiliary and Fuel Handling Building was decontaminated sufficiently to permit regular occupancy and the Containment Building vented of radioactive gas. Another two years passed before radiation levels in the Containment Building were reduced to safely permit prolonged occupancy, particularly in those areas allowing access to the reactor. Three more years elapsed, while scientists and engineers worked on the polar crane, opened the reactor, and designed, built, and tested hardware for removing, packaging, and transporting core debris. And more than three years were needed to dismember, package, and transport the core to the Idaho National Engineering Laboratory for storage and research.

After the accident, GPU Nuclear began cleaning and decontaminating the Auxiliary and Fuel Handling Building. The Auxiliary and Fuel Handling Building is really two distinct facilities separated by a common wall. The

Auxiliary Building contains tanks, pumps, piping and other equipment used to process and store water for the reactor and primary cooling system. That building also is used for treatment of radioactive wastes. The Fuel Handling Building contains equipment for moving and storing nuclear fuel. Most of the hardware, floors, and walls of the Auxiliary Building were contaminated when the sump pump in the basement of the Containment Building began discharging spilled reactor coolant into the sump of the Auxiliary Building. As a result, GPU Nuclear elected to install the commercially available EPICOR-II demineralizer system for processing both spilled water in the Auxiliary Building and water used in scrubbing floors, pipes, and other surfaces.

The EPICOR-II demineralizer system was comprised of three EPICOR ion exchange prefilters arranged in series. As contaminated water passed from one prefilter to the next, progressively more and more radioactive contaminants - principally cesium and strontium - were removed. The cleaned water was stored until needed for other cleaning and decontamination tasks. Once a prefilter was loaded with radioactive materials, it was removed from service, moved from the Auxiliary Building in a shielded container, and stored in a temporary concrete building near the Unit-2 complex.

By the time the Auxiliary Building was decontaminated, 50 EPICOR-II prefilters had been used and placed in storage. Several prefilters contained approximately 2,200 curies of radioactive isotopes and had a radiation field approaching 1,000 Roentgens per hour on the exposed surface. Since the prefilters individually contained more radioactivity than was permitted for disposal as commercial low-level radioactive wastes, they had to be either repackaged in high-integrity containers or their contents immobilized in concrete or other durable media, as specified in regulations of NRC. Neither situation seemed workable because, in 1981, there was no licensed high-integrity container which could accommodate something as large and radioactive as an EPICOR-II prefilter. An EPICOR-II prefilter is cylindrical, about four feet in diameter, five feet high, and contains about 35 cubic feet of organic resins or organic resins with zeolite. Likewise, immobilizing the contents of an EPICOR-II prefilter would increase significantly the volume of radioactive wastes disposed by GPU Nuclear. Unnecessary proliferation of radioactive wastes was contrary to recommendations outlined in the Programmatic Environmental Impact Statement by NRC. DOE agreed to accept the 50 EPICOR-II prefilters under terms of the interagency Memorandum of Understanding and use them as research materials, in order to develop a method whereby they could be disposed as low-level radioactive wastes.

Two EPICOR-II prefilter were retrieved from storage and transported to Battelle Columbus Laboratories in Ohio for examination. That laboratory discovered gases escaped when the prefilters were opened and residual liquids inside were acidic. Immediately, questions were raised about potential rusting and over pressurization of each prefilter in storage at TMI. DOE asked EG&G Idaho to design and build a device which would vent each prefilter of gases and replace the internal atmosphere with an inert gas, before transporting the prefilter by truck from TMI to Idaho National Engineering Laboratory, or INEL. EG&G Idaho responded to the request and delivered to GPU Nuclear the Prototype Gas Sampler, which remotely opened the prefilter, sampled and analyzed internal gases, and replaced the atmosphere in the prefilter with argon. All EPICOR-II prefilters were transported safely by truck to INEL, where they were placed in storage.

Radioactive materials brought to INEL are used in answering questions important to the government and nuclear industry. The EPICOR-II prefilters afforded DOE some unusual research opportunities. For example, engineers and scientists were concerned about rates of internal corrosion of the steel containers, the behavior of organic resins after receiving internal radiation doses in excess of that accomplished in laboratory tests, and development of a high-integrity container which would facilitate disposing of the prefilters as low-level radioactive wastes.

EG&G Idaho devised ways of remotely collecting samples of resins and zeolites in selected prefilters and analyzing them for chemical and physical changes in resins. Analyses revealed that resins began to structurally change in radiation fields less intense than assumed by NRC. That discovery encouraged NRC to fund continued research in degradation of irradiated resins and initiate revision of regulations concerning immobilization of resins before disposal. EG&G Idaho also succeeded in remotely transferring resins from an EPICOR-II prefilter to an empty EPICOR liner. The emptied prefilter was decontaminated, then metallurgical samples were cut from the sides. The samples were examined and shown to have little corrosion. That finding eliminated further concerns about uncontrolled rusting of EPICOR-II prefilters during storage.

Critics of TMI and DOE claimed that the EPICOR-II prefilters could not be disposed as low-level radioactive wastes within the present regulatory framework. They argued that a high-integrity container large enough to accommodate a prefilter could not be built or licensed. DOE, two of its national laboratories, several private companies, and a state regulatory authority believed otherwise. EG&G Idaho asked Sandia National Laboratories to assist in developing criteria for a high-integrity container suitable for the prefilters. EG&G Idaho contracted Nuclear Packaging, Inc. of Federal Way, Washington, to design the high-integrity container based upon criteria provided by Sandia National

EG&G Idaho also contracted Nuclear Packaging, Inc. to construct two prototype high-integrity containers. One was built and drop-tested from 10 feet at the manufacture's facility and the other used in additional testing at INEL. The Department of Social and Health Services of the State of Washington requested that the second prototype at INEL be drop-tested from 30 feet. After that test, the State of Washington issued a Certification of Compliance for the concrete high-integrity container based upon technical review and and advice from NRC. Thus, the first-of-a-kind reinforced concrete high-integrity container was used in the disposal of 46 EPICOR-II prefilters as Class "C" low-level radioactive wastes in the commercial nuclear waste disposal facility in the State of Washington. The other four prefilters were disposed as government research wastes in a facility at INEL, after completion of research sponsored NRC.

Once the Auxiliary Building at TMI was decontaminated, attention shifted to decontamination of the Containment Building. The first task was to drain and clean the 600,000 gallons of contaminated water in the basement.

GPU Nuclear designed and built into the EPICOR-II demineralization system another filtration system for removing cesium and strontium from the water in the Containment Building. The new system was inserted in the process line between the Containment Building and EPICOR-II system in the Auxiliary Building. The filters, or vessels, resembled a large, household water softener. Internally, the vessel was filled with zeolites, which look like granulated cereal or dry pet food. Zeolites have strong affinities for certain radioactive materials.

Since those vessels would be capturing and concentrating large quantities of strontium and cesium, they were arranged in series within the "B" Pool of the Fuel Handling Building, hence the name "submerged demineralizer system" or SDS. The pool provided shielding to workers and equipment against intense radiation from the loaded vessels without interfering with access to needed facilities. Water leaving the SDS vessels was sent to the EPICOR-II demineralizer system for final cleaning before storage in a special tank.

Originally, specifications for SDS limited each vessel to containing about 10,000 curies of radioactive isotopes. However, studies by DOE at the Oak Ridge National Laboratory indicated that each vessel could be safely loaded to many times that number of curies, thereby reducing both the number of vessels needed to process that 600,000 gallons of water and volume of wastes produced.

After all the water was processed, 19 vessels of wastes had been produced. Some vessels contained about 112,000 curies of radioactivity each, with radiation fields approaching a 100,000 Roentgens at the exposed surface. That was substantially more radioactivity than had been managed in the disposal of the EPICOR-II prefilters. Consequently, DOE was faced with two challenges: First, it had to figure out how to control the production of gases in each vessel. And second, it had to decide what to do with the vessels once they were moved from TMI.

When water is placed in a high radiation field, it begins to disassociate into its elemental components. That is, radiation tends to break the chemical bonds binding hydrogen and oxygen by a process termed "radiolysis." That results in the production of hydrogen and oxygen gases. When that process occurs in a closed system like an SDS vessel, there exists the possibility that those gases could eventually overpressurize the vessel or reach concentrations which could instantaneously ignite. In either situation, the end results are undesirable. Therefore, control of gases was accomplished by inserting a catalytic recombiner into the vent port atop each vessel. The recombiner functioned similar to the one used to control concentrations of hydrogen liberated into the Containment Building after the accident. The recombiner chemically reunited the gases into water. That process limited the production of gases in the SDS vessels, making it possible to transport each safely by truck in a commercially available cask from TMI to the Pacific Northwest Laboratories near Richland, Washington.

At Pacific Northwest Laboratories, the SDS vessels were used in several experiments and demonstrations. For example, the contents of three SDS vessels were mixed with glass-forming compounds, transferred to a special stainless steel container, and heated to where the contents of the canister fused into a solid mass of glass. Heretofore, radioactive zeolites had not been immobilized in glass, nor had the contents of a canister been fused in place within a container.

Some SDS vessels were used in remote handling experiments, which demonstrated that objects as radioactive as those vessels could be transferred dry from one container to another. That demonstration provided an alternative to submerging high radiation sources in water before making transfers between containers. The demonstration also avoided the inconvenient, expensive, and time consuming task of decontaminating wet hardware.

At the conclusion of the experiments at Pacific Northwest Laboratories, each SDS vessel was placed in a concrete overpack in preparation for storage below ground. One overpack was equipped with instruments for continuous monitoring of radiation fields, temperatures, and pressures of the SDS vessel.

Once the Containment Building was decontaminated to the point where technical personnel could regularly occupy the facility, a balance had to be struck between meeting the needs of the operating utility and various government agencies. GPU Nuclear focused on decontaminating Unit-2 to where NRC would agree to change the license for Unit-2 to reflect the facility being defueled. That would benefit economically the utility and its customers. On the other hand, the government and industry were interested in understanding the accident and measuring its effects on nuclear equipment. That knowledge would lead to construction of better equipment, safer operation of nuclear facilities, prevention of similar incidents, and smoother and more efficient recovery operations should other incidents occur. That meant all parties had to agree on what was to be done, in what priority things would be done, and against what schedule. Consequently, not all equipment could be examined nor all research samples collected. Only those things that fit the schedule of the utility and resources of all interested parties were pursued.

During an accident, control and safety of a nuclear reactor depends on instruments and electrical equipment functioning properly. When instruments or equipment malfunction, control of an accident becomes very difficult. Such was the case at TMI in March 1979. It is not surprising that DOE, NRC, the Electrical Power Research Institute, and electrical utilities in general were eager to recover and test instruments, and electrical connectors and cabling from inside the Containment Building, as soon as possible after initial entries. Recovery of those types of hardware were particularly important, because they initially were subjected to an intense steam environment as the Unit-2 reactor leaked coolant into the Containment Building. Then, they were subjected to the burning of hydrogen gas. Finally, they experienced several years of intense irradiation and high humidity.

Information gained from examining equipment subjected to those hostile environments was recognized as important in improving standards for fabricating and qualifying new electrical equipment. It proved invaluable to understanding how equipment presently in use at other nuclear power stations would perform in an accident. Likewise, that information revealed modes of instrument failure during and after an accident. And lastly, it was useful in assessing the safety of other nuclear reactors using the same or similar equipment.

Of the many pieces of electrical equipment removed from containment, examined and tested in laboratories, two pieces yielded especially interesting and valuable information:

> At the top of the Containment Building is the polar crane, whose operation was mandatory for moving the large pieces of equipment in and around the reactor. After the accident, numerous questions were raised regarding the safe use of the crane in subsequent cleanup and defueling operations. Consequently, examination and recertification of the crane was prerequisite to future actions. The pendant cable, which contains control switches for operating the polar crane, was suspended near the center of the Containment Building during the accident. The outer surface of the cable showed varying degrees of thermal damage from the hydrogen burn. Some parts were charred, some discolored, and others undamaged. Testing sections of the cable showed that the accident and post-accident environments had little or no effect on the material properties of the inner insulation of the cable, or the ability of circuits inside to perform their intended functions.

At the top of the enclosed stairwell in the Containment Building, there is a radiation monitor, which is designed to provide operators with information about radiation levels in the event of a loss-of-coolant-accident. During the accident, operators used that monitor to declare a General Emergency at TMI, when radiation levels in the Containment Building reached preset limits causing the instrument to alarm. Examination and testing of the monitor later revealed that radiation levels measured by the monitor during the accident probably were inaccurate, and those measured long after the accident drastically in error. Part of the inaccuracy during the accident was attributed to the instrument being shielded by thick pieces of lead and stainless steel installed for the purpose of protecting electronics inside the monitor. Inaccuracies during the post-accident period were attributed to intrusion of moisture into the monitor through an improperly installed seal during assembly, and degradation of electronics by prolonged irradiation. The moisture short-circuited some electrical systems and the prolonged irradiation adversely affected certain transistors in the instrument. Based on information gained from studying the monitor in the Containment Building of Unit-2, NRC changed specifications for radiation monitors installed in the containment buildings of operational reactors.

While scientists and engineers were examining electrical cabling and instrumentation in the Containment Building, others were busy examining the inside of the reactor, and planning for opening the reactor and removing the damaged core. As mentioned earlier, EG&G Idaho provided a television camera and developed a sonar device, both of which were used initially to explore inside the reactor. That "quick look" equipment provided the information needed in planning removal of the head and lifting the plenum assembly from inside the reactor. It also set the stage for collecting samples of debris from atop the damaged core.

In planning for removal of the head and lifting the plenum assembly, questions were raised by participants in and critics of activities at TMI about the capability of the polar crane to safely lift those large, heavy pieces of steel.

Although the electrical cabling and switching electronics of the crane seemed operable, GPU Nuclear refurbished and, where necessary, replaced moving parts, before load testing and requalifying the crane to original specifications. That effort took more than a year and delayed opening the reactor until July 1984.

In preparing for lifting the head, a significant amount of housekeeping had to done around the top of the reactor and in the empty fuel transfer canal surrounding the top of the reactor. Such things as insulation, fans, electrical cabling, and various pieces of hardware were removed. That eliminated some radiation sources and simplified working around the top of the reactor. A leak tight barrier was built across the deep end of the fuel transfer canal. The barrier facilitated keeping the deep end of the canal filled with water. Also, an emergency flood system was installed to provide water for additional radiation shielding or contamination control around the top of the reactor.

Next, the large nuts and studs used in attaching the head to the body of the reactor had to be cleaned, decontaminated, and lubricated, before loosening. Each stud was about 12 inches in diameter and there were 60 of them around the top of the reactor.

Elaborate precautions were taken by GPU Nuclear to shield workers from excessive radiation and protect against further contamination of the work area around the top of the reactor. The head was draped with "lead blankets" to protect against spreading radioactive contaminants clinging to the head. The head was lifted from the reactor and moved slowly through the air to a storage stand built during construction of Unit-2. The stand was enclosed by a barrier constructed of fiberglass tubes filled with sand, each about two feet in diameter by 22 feet tall. The head was lowered into place atop the stand for storage.

After the head was removed, the holes in the flange once occupied by the 60 studs were plugged and a steel ring - called the internals indexing fixture - attached to the flange. That fixture was used in guiding the plenum assembly into the reactor during initial assembly. The fixture was made leak tight so that the water level in the open reactor could be raised, providing more shielding against radiation.

Immediately below the head of a reactor was the plenum assembly. It was constructed of stainless steel, measuring nearly 14 feet in diameter by 12 and a half feet high, and weighing about 55 tons. The plenum assembly was mostly open spaces interrupted by 69 tubes, containing the leadscrews. The spaces permitted free passage of hot water from the core to pipes leading to the steam generators. The leadscrews manipulated control rods in each fuel assembly, which, in turn, increased or decreased nuclear reactions in the core.

When constructed, the plenum assembly and part of the adjacent core support assembly were machined to close matching tolerances, both keyed to fit into the reactor vessel in a certain way. That way, they aligned properly to the fuel and control rod assemblies below. During the accident, portions of the plenum assembly experienced localized melting and thermal expansion far in excess of designed clearances. That caused physical distortion of some components and created concern about the structures possibly binding during lifting the plenum assembly from the reactor. Since the polar crane would lift and remove the plenum assembly, any binding might exceed the lifting capacity of the rigging.

Four specially designed hydraulic jacks were attached at equal intervals around the top of the plenum assembly. Each one extended downward through a narrow space to a flange on the core support assembly. In unison, the four jacks, each capable of lifting 60 tons, were activated, raising the plenum assembly 7 and 1/4 inches without difficulty.

After raising the plenum assembly, a temporary work platform was installed over the internals indexing fixture. From that platform, technicians, using small television cameras, inspected all surfaces of the plenum assembly. With the aid of long handled tools, end fittings and pieces of fuel rods were dislodged from the underside of the plenum assembly. Those pieces of core debris simply fell into the cavity of the core. Once the plenum assembly was cleaned of core debris, the temporary work platform was removed and preparations began for final lifting and storage of the plenum assembly.

Ordinarily, the plenum assembly is removed from the reactor vessel by attaching a lifting device to the three lifting lugs projecting upward from the plenum assembly, then connecting the system to the hook of the polar crane. Because the plenum assembly of Unit-2 experienced some damage and thermal distortion, engineers of GPU Nuclear decided to not use the lifting lugs. Instead, they devised a method whereby the lifting device was attached at three points to the underside of reinforcing structures in the top of the plenum assembly. Once attached, the device was connected to the polar crane. The plenum assembly was lifted free of the reactor and moved to the deep end of the fuel transfer canal. There, it was lowered onto a submerged storage stand. Water in the deep end of the canal provided shielding against radiation.

With the reactor open, defueling began in earnest. First, a rotatable work platform was installed over the internals indexing fixture. The platform shielded technicians from radiation from the core and provided access to the core through a slot in the floor. Parts of a carousel-like device were lowered into the vessel, assembled, and attached to the side of the platform. Five canisters were lowered into the carousel and readied for filling with core debris. The canisters were designed specifically for receiving, transporting, and storing the core debris. The technicians, using long handled tools, began collecting the loose debris lying on top of the core and placing it in canisters. The loose fuel rod segments, pieces of collapsed fuel assemblies, and rock-like rubble were placed in canisters. Smaller pieces of rubble were vacuumed into canisters. Fine debris suspended in the water was removed by filteration devices installed in some canisters. Eventually, all loose materials on top of the core were removed and packaged in canisters.

Following the "quick look" and sampling of the core three years earlier, EG&G Idaho began developing drilling hardware which could drill through the entire core, regardless of type and density of materials encountered. The intent was

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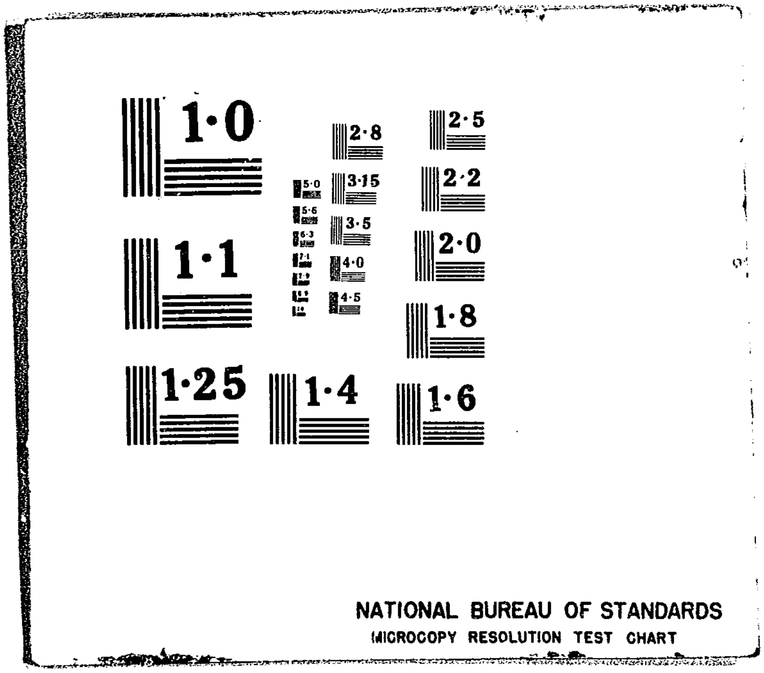

to collect several vertical samples from the core for use in studying causes and effects of the accident.

After testing several types of drilling bits, the "Chrisdril" manufactured and sold by Christensen Mining Products of Salt Lake City was selected. The Chrisdril successfully drilled through random layers of zircaloy rods, Inconel and stainless steel structures, hard-fired alumina plating, ceramic materials, concrete, and gravel. The ability of that drill to penetrate those media was made possible by equipping the cutting face with large, diamond-faced tungsten carbide teeth.

The Chrisdril was attached to a modified commercial drilling machine, which was equipped with a special drilling spindle and chuck. The spindle and chuck could accommodate several sizes of drill pipe and instantaneously change vertical pressures of the bit. Because the core media through which the bit would pass were unknown, and because each medium dictates torques and loads on the drilling system, a computer-based control system was incorporated into operation of the drilling machine. That system, plus the special spindle, made it possible to automatically manipulate the drill through media of unknown densities and consistencies without operator intervention.

After the loose debris was removed, the drilling system was installed on the work platform above the reactor. Ten samples of materials were drilled from the core and placed in canisters. GPU Nuclear used small television cameras to inspect spaces below the core. The drilling system was removed from the work platform and stored nearby. The canisters with samples were transferred to the Auxiliary and Fuel Handling Building by way of the flooded portion of the fuel transfer canal.

Supposedly, the way was clear for GPU Nuclear to complete defueling operations. But, because clarity of the water in the vessel had been deteriorating for weeks, technicians could not see what to remove. Nor could they brake or penetrate the surface of the core with long handled tools.

After some testing, GPU Nuclear determined that the clouding agent in the reactor was an uncontrolled biological growth. Before any more core debris could be removed, the growth of microorganisms, feeding on the organic materials in the water, had to be controlled. GPU Nuclear controlled the organisms by treating the water with chemical additives and filtering the treated water through a series of sand-like filters. Soon, clarity was restored to the water in the reactor. The same chemical treatment was administered to canisters filled with core debris. That was done as a precaution against potential corrosive actions by some bacteria.

GPU Nuclear reinstalled the core drilling machine and drilled as many overlapping holes through the crust as possible. Literally, an eight-foot circular section in the center of the core was drilled into rubble. Loose debris left behind after drilling was loaded into canisters and removed from containment. The technicians again started working with manual tools, prying out remnants of the core. The remants consisted mostly of fuel rods, structural hardware, and endfittings of the lower portions of fuel assemblies. Remnants, likewise, were placed.in canisters.

Each time an area above was disturbed by technicians, some debris left behind by the drill moved downward through open spaces between stubs of fuel rods. That meant more and more core material was being displaced to lower portions of the core and into the lower plenum. In fact, another 20 tons of debris was added to the 20 tons displaced to the lower plenum during the accident.

After the core was removed, the lower core support assembly was cut apart and removed, using the drilling machine and a remotely operated plasma arc cutting torch developed for GPU Nuclear by Power Cutting, Inc. near Chicago. Pieces of the support assembly containing core debris were placed in canisters. Pieces free of debris were removed and stored outside the reactor until completion of defueling operations. At that time, some pieces were packaged and sent to INEL for possible examination at a later date. The debris in the lower plenum was scooped or vacuumed up and put in canisters for storage at INEL.

Although the principal focus of the participants in GEND was gaining access to the reactor and removing the damaged core, much attention also was given to transporting the core from TMI to INEL for storage and research. According to regulations of the Nuclear Regulatory Commission, materials containing greater than trace amounts of plutonium must be contained behind two barriers. Since all nuclear fuels in reactors progressively accumulate trace amounts of plutonium in the course of normal use, containment of that substance is not difficult. The metal, or zircaloy, of a fuel rod in a fuel assembly functions as the first level of containment. The cask used to transport the spent fuel provides the second level of containment. Thus, the rule established by NRC is complied with in the routine transport of spent nuclear fuel.

In the case of the damaged core of Unit-2, however, the zircaloy of fuel rods was breached during the accident. As a result, the first containment barrier was lost. No commercial cask available provided two levels of containment. That meant either an existing cask had to be modified or a new one designed, built, and licensed specifically for transporting core debris from TMI to INEL. In 1984, EG&G Idaho contracted with Nuclear Packaging, Inc. to design, construct, test, and license a new cask.

Although that may sound like a simple undertaking, detractors and some politicians claimed the regulatory and political climates were not conducive to building and licensing a new cask. In general, they were correct, because designing, licensing, and building any cask took several years. A totally new design was construed as practically impossible and potentially an unacceptable delay to the defueling schedule being followed by GPU Nuclear. But, early involvement of NRC in planning for a double containment cask and following suggestions by NRC to subject a model of the cask to a series of drop tests effectively shortened the licensing time to the point that the NuPac 125-B Rail Cask was designed, tested, built, and licensed between June 1984 and April 1986 - a period of less than two years.

A 1/4-scale model of the cask was drop-tested five times by the Transportation Technology Center of Sandia National Laboratories. The first three drops were from 30 feet onto an unyielding surface, and the last two were from 40 inches onto a two inch puncture pin. Although testing damaged the overpacks on the model, design of the overpacks presupposed some deformation and damage from each test. Integrity of the cask model, however, was not compromised by or during drop testing.

Following the drop tests at Sandia National Laboratories, a full scale model of the canister being used at TMI was drop-tested four times by the Chemical Technology Division of the Oak Ridge National Laboratory. Unlike the tests at Sandia, the canister was placed inside a steel pipe to simulate placement inside the rail cask and the pipe fitted with Styrofoam pads to simulate impact limiters used in the rail cask. The assembly was dropped from 30 feet to simulate severe accidents. Analysis of the canister after the tests showed no external damage. Damage to internal parts was limited to slight bending of some pieces, but nothing that would compromise integrity of the canister.

Results of the drop tests were included in the Safety Analysis Report for the NuPac 125-B Rail Cask. That report was submitted by Nuclear Packaging to NRC, as part of the licensing application for the cask. DOE, confident enough that the NuPac 125-B Rail Cask would be licensed, authorized construction of two NuPac 125-B Rail Casks, while NRC was reviewing the application. Consequently, the two casks, plus all the loading and unloading hardware, were in place at both TMI and INEL in plenty of time to avoid disrupting the defueling schedule of GPU Nuclear. Another rail cask was built later by Nuclear Packaging and leased to GPU Nuclear. Thus, three casks were used in transporting core debris.

It is noteworthy that the casks and loading hardware were tailor-made to fit in the Truck Bay between Units 1 and 2 at TMI. Before that equipment was moved to TMI from near Seattle, it was fully assembled and tested at the Hanford Engineering Development Laboratory near Richland, Washington. Technical personnel from GPU Nuclear used that demonstration for testing procedures and training.

The NuPac 125-B Rail Cask is a stainless steel vessel within a stainless steel and lead composite vessel. Each vessel is made leak-tight by a double O-ring bore seal in its lid. The inner vessel contains seven tubes, each sized to accommodate a canister from TMI. Although the canister effectively is a third level of containment for core debris during transport, no credit is taken for that barrier in design and operation of the cask. In other words, it is a safety feature apart from the cask.

Spaces between tubes and structural components are filled with a special neutron absorbing material, which precludes the possibility of a criticality during an accident. Impact limiters, or energy absorbers, at the ends of each tube to cushion canisters in case of sudden decelerations. The outer vessel is constructed of two circular pieces of stainless steel fitted one inside the other. The space between the two pieces is filled with lead, which provides shielding against radiation emitted by contents of the canisters. Large energy absorbing overpacks are fitted over ends of the cask to protect the cask and contents from potential damage in case of a transportation accident.. The cask with overpacks is 23 feet long and 10 feet in diameter across the overpacks. The system weighs about 180,000 pounds, when fully loaded and assembled atop the railcar. That is approximately the same weight as a fully loaded, stretched Boeing 727 airliner, including a full complement of passengers, crew, cargo, and fuel at takeoff.

When the decision was made to develop the NuPac 125-B Rail Cask, the last technical challenge to transporting core debris from TMI to INEL was interfacing loading equipment with the Truck Bay in ways that would not infringe on space dedicated to Unit-1 or interfere with the relicensing of Unit-1. Accordingly, the equipment was designed and built to permit unrestricted passage of the rail cask and railcar, manipulate the cask, and satisfy safe-shutdown earthquake criteria within the confines of the Truck Bay.

As noted earlier, once a canister was loaded with core debris, it was sealed, withdrawn from the reactor vessel into a shielded transfer device, and moved to the deep end of the fuel transfer canal. There, it was lowered into an up-ender, or device which rotates the canister from vertical to horizontal, at the bottom of the canal. A transfer device then shuttled the canister through the fuel transfer tube in the wall of the Containment Building to another up-ender in the "A" pool in the Fuel Handling Building. There, the canister was rotated to vertical and placed in the storage rack. At the appropriate time, the canister was dewatered using argon gas, leak-tested and monitored for leaks, and readied for shipment. The fuel transfer cask was used to load the rail cask.

When a rail cask was available at TMI for loading, the overpacks were removed outside the Truck Bay. The cask on a railcar was pushed into the Truck Bay. The cask on its transport skid was disconnected from the railcar and lifted by the cask unloading station. The railcar was withdrawn from the Truck Bay, and the cask and skid lowered to the floor. The cask was rotated to vertical by hydraulic lifters and secured to a work platform. The cask was opened. And the shielded loading collar installed on top of the cask. The mini-hot cell withdrew and held a shield plug from a tube in the cask. The fuel transfer cask retrieved a canister ready for.

shipment from the "A" pool, transferred it to the cask, and lowered it into the open tube. The mini-hot cell returned the plug to the filled tube. That transfer and loading sequence was repeated six more times until the cask contained seven canisters. After loading was completed, lids of the cask were replaced and each vessel leak-tested, ensuring that the cask was assembled correctly. The cask was returned to horizontal and lifted onto the railcar. The overpacks were placed on the rail cask. The package was surveyed and certified for release to EG&G Idaho by GPU Nuclear at the front gate of TMI.

Before acceptance by EG&G Idaho, each cask and its railcar were inspected by representatives of Conrail, the Federal Railroad Administration, and EG&G Idaho. The transportation officer of EG&G Idaho accepted custody of the loaded casks on behalf of DOE, after attendant transportation documentation for each cask was checked. DOE honored requests from various states to inspect the train while in route to INEL. The train was inspected by representatives of the States of Ohio, Indiana, Illinois, Missouri at prearranged stops along the rail route. Occasionally, the train was inspected by a representative of the State of Kansas.

In consultation with various railroads, DOE evaluated the quickest and safest rail routes between TMI and INEL. It reached agreements with Conrail - or Consolidated Rail Corporation - and Union Pacific Railroad for transportation of the core debris in the NuPac 125-B Rail Casks. Those rail companies were selected partly because of their demonstrated safety records with hazardous wastes, partly because their combined route is one of the shortest distances between TMI and INEL, and partly because the combined route was composed of top quality trackage certified by the Department of Transportation for use in transporting hazardous wastes. That trackage also was certified independently by the Federal Railroad Administration for the same purpose.

After all inspections were completed at TMI, the Conrail locomotive attached to the train. The train left through the front gate of TMI. Conrail agreed to provide expedited - or exclusive-use - rail service from TMI to East St. Louis, Illinois. At that point, Union Pacific initiated the same service, assuming responsibility for transporting casks to the Scoville siding at INEL. Conrail restricted the speed of the train to 30 miles per hour between TMI and East St. Louis, as a matter of corporate policy for transporting hazardous materials. Union Pacific had a higher speed restriction of 50 miles per hour between East St. Louis and INEL.

DOE fully recognized that transporting core debris from TMI transcontinentally to INEL would be a sensitive public issue. EG&G Idaho was requested to write procedures which outlined the process whereby governors of states along the rail route would be notified of the planned action to transport that material through their jurisdictions. Those procedures outlined the rationale used in selecting the rail route, explained the communication network used to monitor casks in transit, and described emergency communications used in case of an unusual occurrence along the route. First-time notification was issued to each state 45 days before initiating the transport campaign. Thereafter, each state was notified in writing seven days before the train left TMI and telephoned if the schedule of the train varied more than four hours from that initially transmitted by letter.

Public announcement of the rail route between TMI and INEL initiated a flood of public inquiry. Inquiries were received from mayors, fire chiefs, police departments, citizen groups, state officials, congressmen, and senators to mention a few. The citizenry in several communities along the rail route voiced desires that the core debris be transported via alternate routes around their domains.

Seemingly, there is public perception that rail routes can be changed here and there easily and conveniently to avoid this or that population center. Generally, decisions to "avoid my town" are impractical. Alternate routes around cities or municipalities comprise lesser quality trackage. The use of that trackage would increase transport time and add to the risk of transporting the core debris. Regulations promulgated by the Department of Transportation specifically direct railroad companies to transport such materials on high quality, mainline trackage.

Upon arrival at the Scoville siding at INEL, the Union Pacific locomotive was disconnected. The INEL locomotive immediately attached to the train and hauled it to the Central Facilities Area. Overpacks of a cask were removed and stored. The gantry crane lifted a cask and its transport skid from the railcar and transferred them to a truck transporter. Slowly, the cask was hauled approximately 25 miles to the Hot Shop of Test Area North of INEL.

In the Hot Shop, the cask was lifted from the transport skid and placed vertically in a stand designed to contain other large fuel casks. The cask was tested for radioactive contamination and opened manually. Personnel left the Hot Shop. The shield plugs were removed and stored. Canisters were withdrawn individually and conveyed across the Hot Shop to the water-filled vestibule. There, each was lowered slowly into one of two storage modules sitting on a transfer cart. When a module was filled with six canisters, the canisters were refilled with water. The cart passed under the wall of the Hot Shop to the Water Pit located in an adjacent building. The module was lifted from the cart and moved to a preassigned place in the storage rack.

Once in place, canisters were equipped with vent lines, through which residual air in the canister escaped and additional water was added. When the NuPac 125-B Rail Cask was emptied, it was reassembled, returned to its transport skid, and thence to the Central Facilities Area. At Central, the empty cask, with its skid, was returned to the railcar, surveyed for external radioactive contamination, and released to Union Pacific for the return trip to TMI as routine freight. In the meantime, the next cask was readied for transfer to the truck transporter and hauled to the Hot Shop for unloading. The process was repeated until all casks at the Central Facilities Area were emptied, surveyed, and released to Union Pacific for return to TMI as routine freight. Periodically, Union Pacific sends each railcar to its maintenance shop in Pocatello, Idaho for thorough inspection and servicing.

Although canisters are designed for 30 years of storage, DOE plans to retrieve the canisters and process, repackage, or both the core debris into a form acceptable to the federal high-level radioactive waste repository. The schedule for building and operating the repository in the.

State of Nevada is substantially shorter than the planned storage period of core debris at INEL.

In the meantime, a few canisters have been retrieved from storage and returned to the Hot Shop, where their contents were removed. Examination of the contents and detailed analysis of selected samples have resulted in a good understanding of the accident sequence within the Unit-2 reactor:

> During the first hour and 40 minutes, the accident was a small-break loss-of-coolant accident. For that period, the reactor was losing coolant through the relief valve at the top of the pressurizer. Even though the reactor was losing coolant, as long as the reactor coolant pumps remained operational, the core continued being cooled by a mixture of water and steam. At the end of that period, excessive vibration caused shutdown of the pumps. That stopped forced circulation of coolant through the reactor.
>
> During the next hour and 14 minutes, stoppage of forced cooling caused the water and steam

to separate, and gradual boil-off of coolant. The steam generators went dry and coolant level in the reactor decreased sufficiently to begin exposing the core. Radiation monitors in the Containment Building began detecting increasingly higher amounts of radiation. That signaled the beginning failure of fuel rods in the core. Local temperatures in the core exceeded 2,700 degrees Fahrenheit. The ensuing rapid oxidation of zircaloy increased core temperatures to greater than 3,800 degrees Fahrenheit. That generated large quantities of hydrogen gas. As temperatures exceeded 3,400 degrees Fahrenheit, the zircaloy began to melt. Molten material continued to form as the molten zircaloy began to dissolve the uranium oxide fuel.

During the next 50 minutes, or three hours and 40 minutes after the accident began, brief operation of one reactor coolant pump sent a large quantity of water into the reactor. The hot, highly oxidized zircaloy of fuel rods shattered. Breakage was attributed to a combination of thermal shock and mechanical stresses. Except for fuel assemblies at the very edge of the core, approximately the top five feet of the core fragmented and collapsed into a bed of rubble. That left a large void in the core. In-core thermocouples, or sophisticated electronic thermometers, showed that the surge of water caused localized cooling as coolant percolated through the partially blocked core. Nevertheless, numerous high-temperature regions remained in the central portion of the core. Molten material continued to form in the lower central regions of the core. The molten material was held in place by a crust of solidified ceramic material that acted like a crucible. That was the hard crust encountered beneath the rubble bed during grab sampling and drilling. The high-pressure injection system activated, introducing enough water to cover the core again. But, because the steam and water could not readily penetrate the core, cooling proceeded slowly. At that time, peak temperatures probably exceeded 5,000 degrees Fahrenheit.

During the last three hours of the accident, or five hours after it began, numerous system

> indicators signaled a major and rapid movement of core material. Later inspections showed that those signals were caused by the sudden failure of the crucible-like crust. That failure released molten material into and through the core support assembly to the lower plenum. Water in the lower plenum quenched the molten material, but only after an estimated 20 tons of slag-like debris came to rest on the lower head of the reactor. Continued operation of the high pressure injection system eventually terminated the accident five hours after it began. The remaining time was used to clear the system of steam and hydrogen, and decrease temperatures to where all pumps could be stopped permanently.

By now, one begins wondering what DOE got from spending $189 million of taxpayers' money. Without a doubt, the return on that investment to the federal government and nuclear industry is inestimable. For example, if DOE tried to conduct an experiment like the one at Three Mile Island, as part of the continuing series of reactor experiments at the Idaho National Engineering Laboratory, construction of a facility like Unit-2 would cost billions of dollars. And, it is reasonable to assume that such a facility would be so burdened with extra safety systems, results from a full-scale experiment would not reflect what happened at TMI or could happen at another reactor. Had the incident at TMI not happened, the realization that nuclear reactors designed and built by the western world are safe despite interference by man might still be fleeting. Other types of experiments might not have arrived at that realization in such a convincing fashion.

That $189 million investment by DOE underlines the value of large investments made since 1950 by the federal government in researching nuclear safety. That is, reactors built and tested at the Idaho National Engineering Laboratory yielded computer codes and design criteria which predicted the behavior of commercial power reactors in accident cases and forced their construction in ways that safely contained the worst case accident. It took the accident at TMI to confirm those predictions. And, it took TMI to change the direction of research in reactor safety from a focus on sudden, large break loss-of-coolant-accidents to small break, long-term accidents such as occurred in Unit-2.

The $189 million investment yielded additional dividends, whose dollar values will not be realized until the nation starts disposing of radioactive materials at the federal repository, sometime in the first decade of the next century. That DOE took time during the cleanup effort at TMI to develop plans for working with the states to ease their apprehensions about transporting core materials from TMI through their jurisdictions will simplify cooperation with states, when it is time to transport high-level wastes through their jurisdictions. The attitude of DOE demonstrates the federal government's concern for the health and welfare of the citizenry and accentuates its recognition of state concerns in nuclear waste issues. If the accident at TMI had not happened, postponing grappling with issues related to transporting high-level radioactive wastes until the next century would be more difficult, perplexing, and expensive! As it is, TMI demonstrated that transporting high-level wastes can be accomplished safely and easily using today's technology according to today's regulations.

How much was returned to the taxpayer by investing that $189 million? Historians and accountants eventually will tell that story.