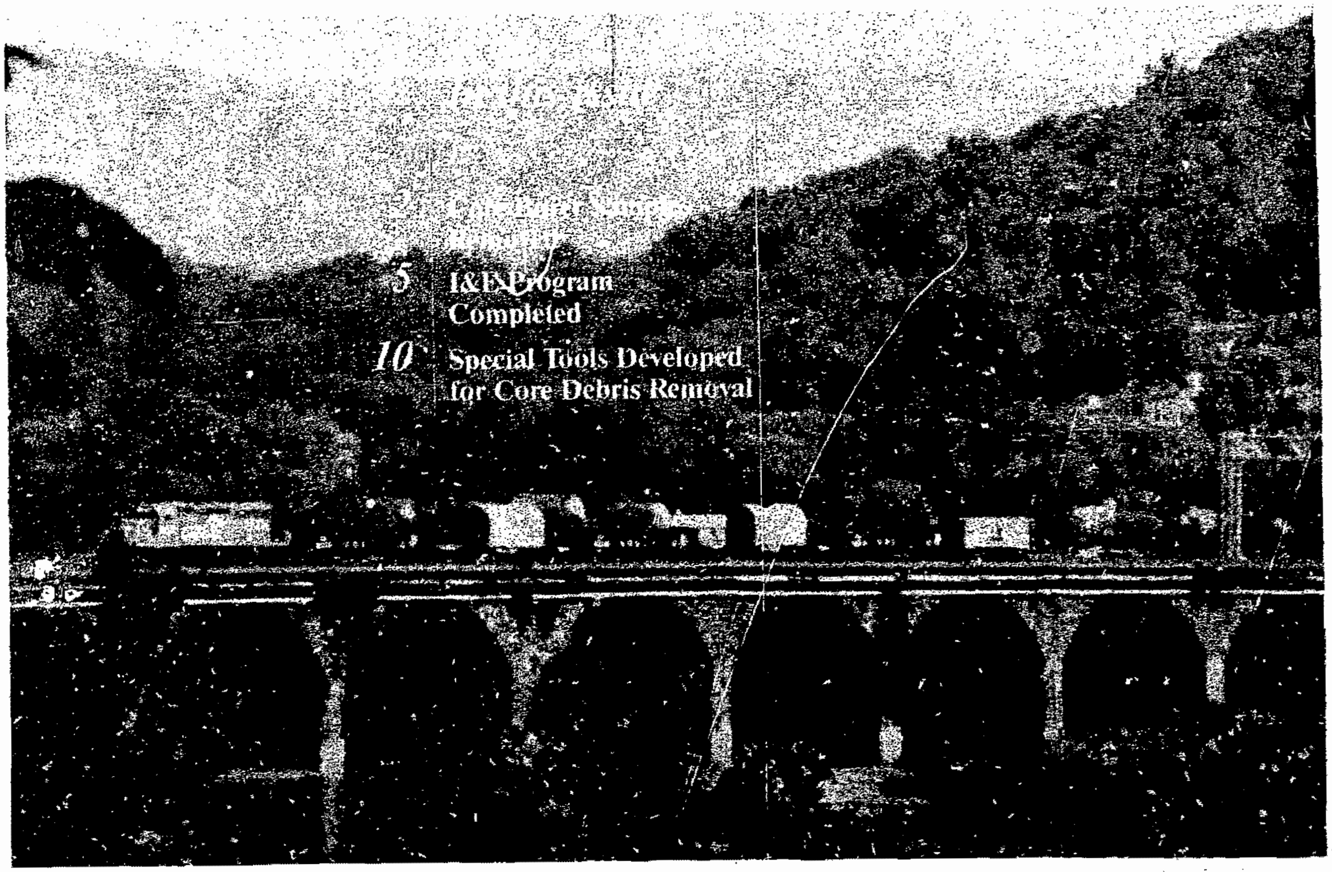
TMI Unit 2 Technical Information & Examination Program

UPDATE

Volume 7, Number 1 December 1986



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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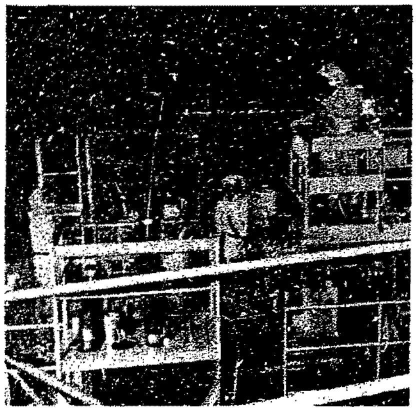
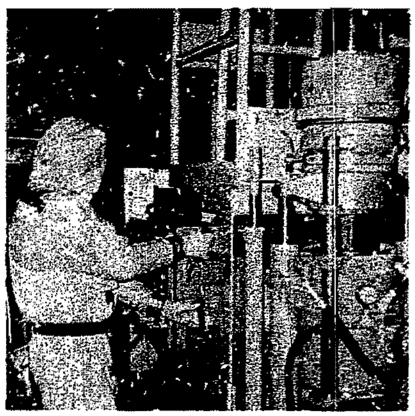
Core Borer Samples Removed



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.

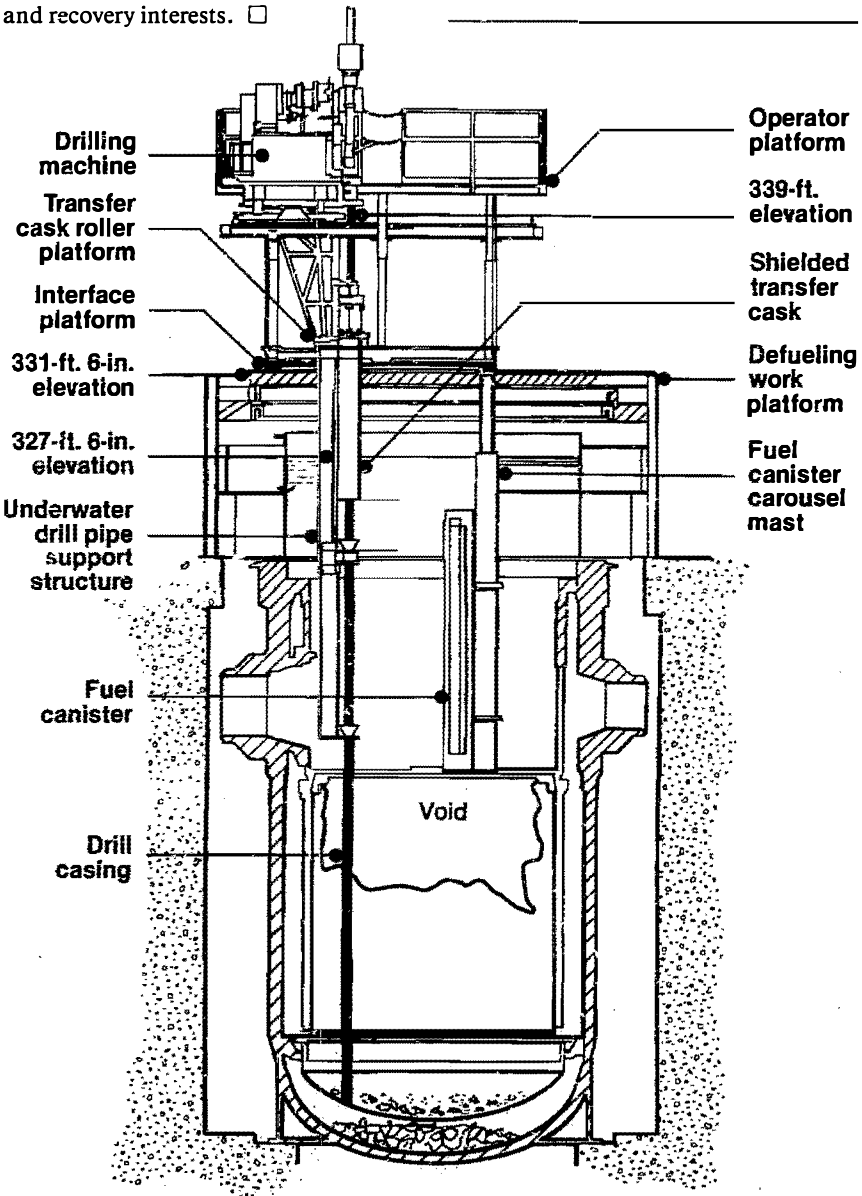
The drill unit was modified to provide precision positioning over the reactor vessel, to incorporate a microprocessor for operational control and safety interlocks, to record drilling parameters (torque, load, etc.), and to provide relevant plant protection functions. For the most part, the sample-cutting 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.

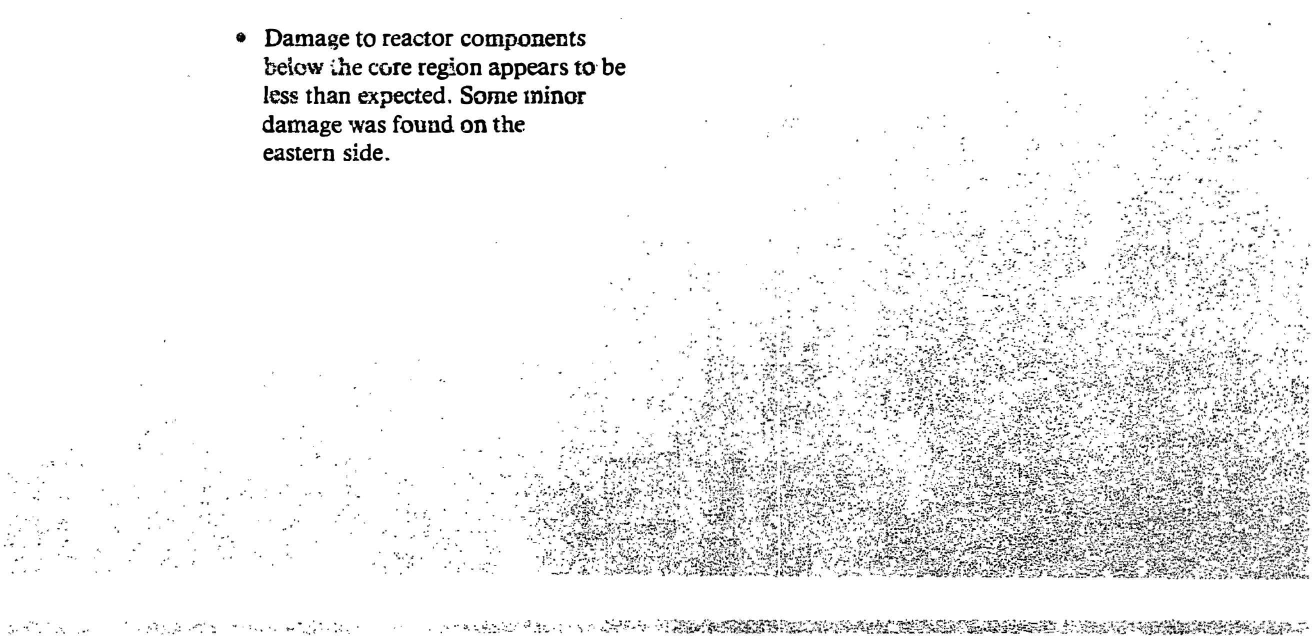
- Damage to reactor components below the core region appears to be less than expected. Some minor damage was found on the eastern side.

- 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:

DOE Site Office
P. O. Box 88
Middletown, PA 17057 □

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

Publications

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M. B. Murphy, G. M. Mueller, and F. V. Thorne, *Examination Results of the Three Mile Island Radiation Detector HP-RT-211,* GEND-014, October 1981.

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L. A. Hecker and H. J. Helbert, *TMI-2 Cable/Connection Program: A Look at In Situ Test Data,* GEND-INF-042, December 1983.

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

C. W. Mayo, et al., *TMI-2 Instrumentation and Electrical Program Final Evaluation Report,* GEND-056 (In Press). ☐

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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