TMI Unit 2 Technical Information & Examination Program

# UPDATE

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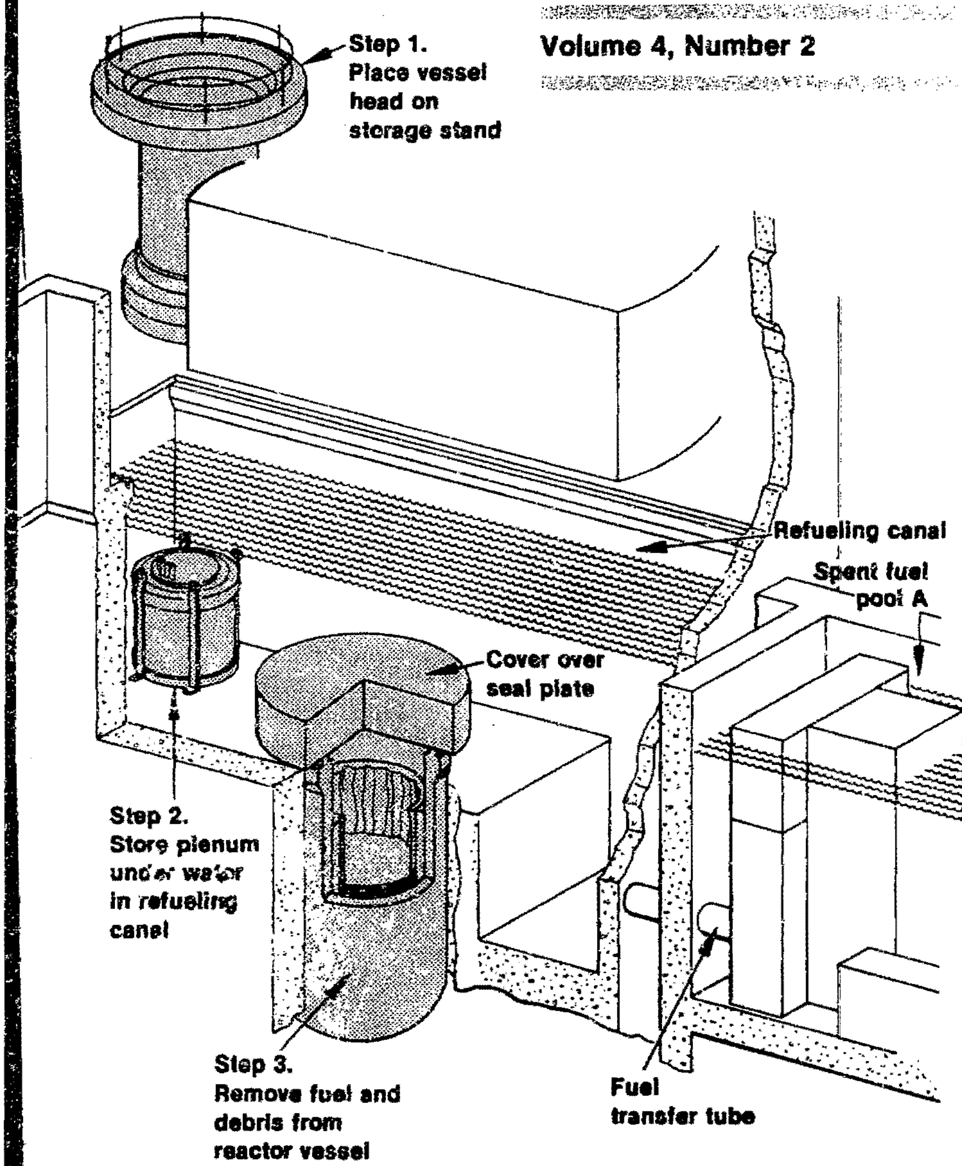


*Figure 1* **This schematic illustrates the three major steps toward defueling Unit 2.**

## TMI Moves One Step Closer to Cleanup with Head Removal

This summer, workers at Three Mile Island (TMI) will take another major step toward defueling the Unit 2 reactor vessel by removing the vessel's head and placing it on the storage stand. After several tests, engineers gave the go-ahead to *remove the head dry—without flooding* the refueling canal. These tests included radiation surveys, sampling, and video inspections of the underside of the head to determine radioactivity, analyze particle makeup, and look for debris that could make removal difficult. *Figure 1* illustrates the three remaining major steps toward disassembly of the reactor at TMI-2: placing the head on the storage stand, storing the plenum under water in the refueling canal, and removing fuel and debris from the vessel.

While these activities, and all of the vital projects in between, are scheduled to take the Technical Information and Examination Program (TI&EP) well into 1987, General Public Utilities Nuclear Corporation (GPU Nuclear) and U.S. Department of Energy (DOE) personnel have done much to bring the program to its present stage, discovering along the way new aspects of accident recovery and answering a number of important questions about the nature and impact of the accident.

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In preparation for head removal, the service structure and refueling canal both were decontaminated, and the lifting and handling equipment was tested. As part of a complete safety evaluation, engineers conducted a head-drop analysis, verifying that the components below could withstand such an impact. Looking for debris that could make head removal difficult, analysts took debris samples from the top of the plenum assembly and found the materials there were nonpyrophoric.

Two final projects in preparing the head for removal are currently underway. Workers are installing the canal seal plate, which will close the gap between the mouth of the reactor vessel and the refueling canal, and they are installing a temporary defueling water cleanup system as a precaution, should an unexpected event require the refueling canal to be flooded for shielding during head lift.

As *Figure 1* illustrates, the second major step toward disassembly is moving the plenum assembly to the shallow end of the refueling canal, where it will be stored under water until its removal. The plan is to first jack the plenum up from its current seated position and then lift it from the reactor vessel using the polar crane.

In 1983, major advances were made in designing tools to inspect and remove the plenum. Four 60-ton hydraulic jacks are being custom designed for the job. From a central pumping station, four operators will hand-pump the jacks, lifting the plenum slowly and in small increments so it may be continuously monitored from top to bottom to check for clearance and prevent jamming. Engineers are already aware from video inspections of the plenum's underside that partial fuel assemblies still hang from the plenum. After initial jacking, workers will knock off these stubs using a tool that is now in the design stages.

Once the plenum assembly is lifted, engineers will wrap it in a large, semi-rigid plastic bag, called the transfer contamination barrier, and place the entire assembly in the shallow end of the refueling canal.

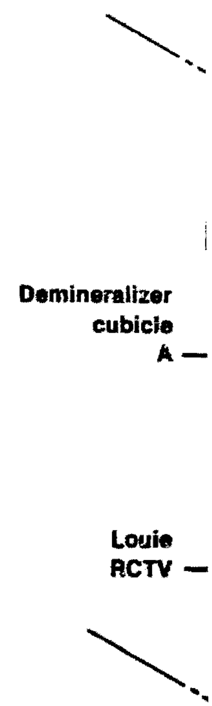
*Figure 1* indicates that the final major step to the TMI-2 reactor disassembly is removal of fuel and debris from the reactor vessel. GPU Nuclear and TI&EP engineers have been concentrating on a number of aspects of this task, including a major defueling water cleanup system, fuel removal tools, and canisters in which to ship the fuel and debris.

The extensive defueling water cleanup system to be installed essentially consists of two subsystems, one to provide water filtration and processing for the reactor vessel and contamination barrier, and a second to provide water filtration and processing for the refueling canal and spent fuel pool A *(see Figure 1)*.

Clearly, a key element to defueling is the fuel removal tooling, to which engineers and designers have been devoting much of their efforts. Westinghouse Electric Corporation, selected as contractor to design and fabricate these tools, suggested two designs for consideration. The first design—a manual, remote defueling system—reflects the technical specifications previously established for the necessary mechanical equipment and vacuum and separation equipment. The vacuum would remove fine materials as small as 10 μm and debris as large as fuel pellets. The system would then separate the debris from the water and load the debris into canisters.

Westinghouse's second proposed design also meets the technical specifications, but it is a more automated approach to defueling. The system would use robotic arms to position a vacuum hose and load into a shredder materials too large for vacuuming. All of the debris then would be pumped in a slurry out of the reactor vessel for separation and canister loading.

After discussing options for fuel canisters, TI&EP and GPU Nuclear representatives selected a design wide enough to hold intact cross sections of fuel assemblies. This canister is, however, shorter than anticipated because engineers do not expect to be shipping any full length fuel assemblies; few if any appear to be intact. A benefit to using this canister design is the potential cost savings; government-owned rail shipping casks may be available for transporting the canisters containing the remains of the Unit 2 core from TMI. □



# Robots Reduce Worker Radiation Exposure

Many work areas in the Unit 2 plant contain large amounts of radioactivity and many surfaces are highly contaminated. While workers are protected with anticontamination clothing and monitored with personnel dosimeters, the effort to keep exposure rates low is a challenging one. Researchers are finding that robots can take the place of humans for many tasks in high radiation areas. A look at two robots, destined for use at TMI, illustrates their useful role in reducing human radiation exposures.

"Left-handed Louie" comes to TMI from Westinghouse Hanford Operations after a long history of remote-control work in a variety of environments. Louie's official name is the Remotely Controlled Transporter Vehicle, or RCTV, but since an anonymous technician during the 1950s scrawled "Louie" on the robot's arm, the RCTV has been known by its more humanlike name. Louie will assist in a crucial waste handling operation at TMI, that of monitoring the removal of the Makeup and Purification System demineralizer resins from their tanks.

During the accident, reactor coolant water flowed through the Makeup and Purification System for nearly 18 hours and deposited significant amounts of contaminants on the resins in the purification system demineralizer tanks. Extensive efforts to determine exactly how contaminated these resins are have shown that cesium activity levels in the resins may far exceed known values for any other accident-generated waste in the plant. Research work reported in both the August and December 1983 issues of the *Update* obtained dose rate readings of 3000 R/h in the A cubicle, and 1000 R/h in the B cubicle.

The contaminants in the resins are soluble fission products. They will be removed through a series of rinsing and elution steps conducted remotely through specially adapted plant systems. Dose rates inside the purification resin tank cubicles are much too high to permit human workers to enter routinely, but the resin tanks must be repeatedly monitored to see if the rinsing and elution steps are decontaminating the resins. Left-handed Louie will be used for the job. As shown in *Figure* 2, Louie will carry a gamma radiation detector into a resin tank cubicle and hold the detector in a predetermined place up against the tank wall. Technicians seated at control panels outside the cubicles can then monitor gamma radiation levels.

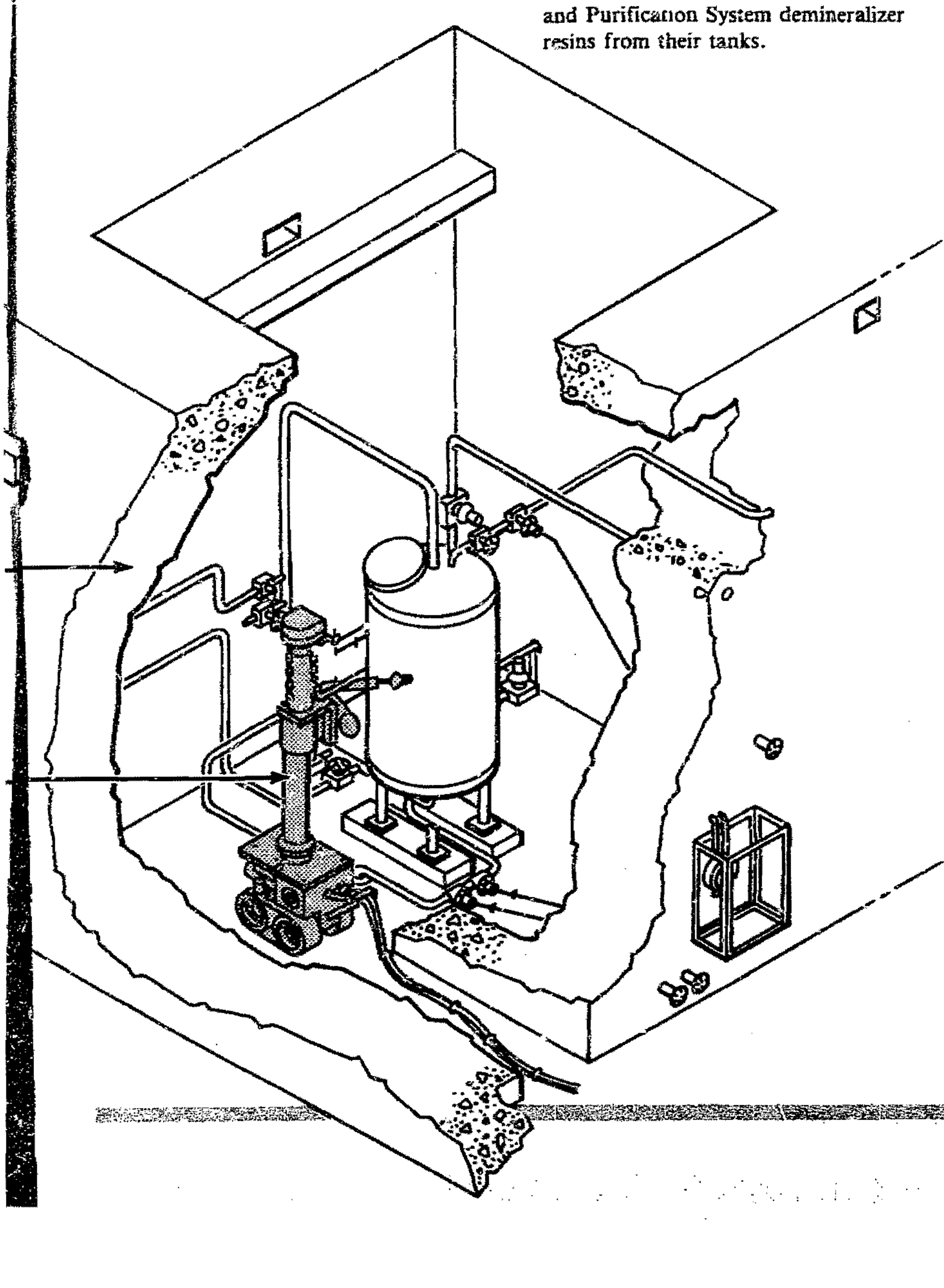


*Figure 2* **Louie will enter the demineralizer cubicle to monitor gamms activity in the resin tank during cesium elution.**

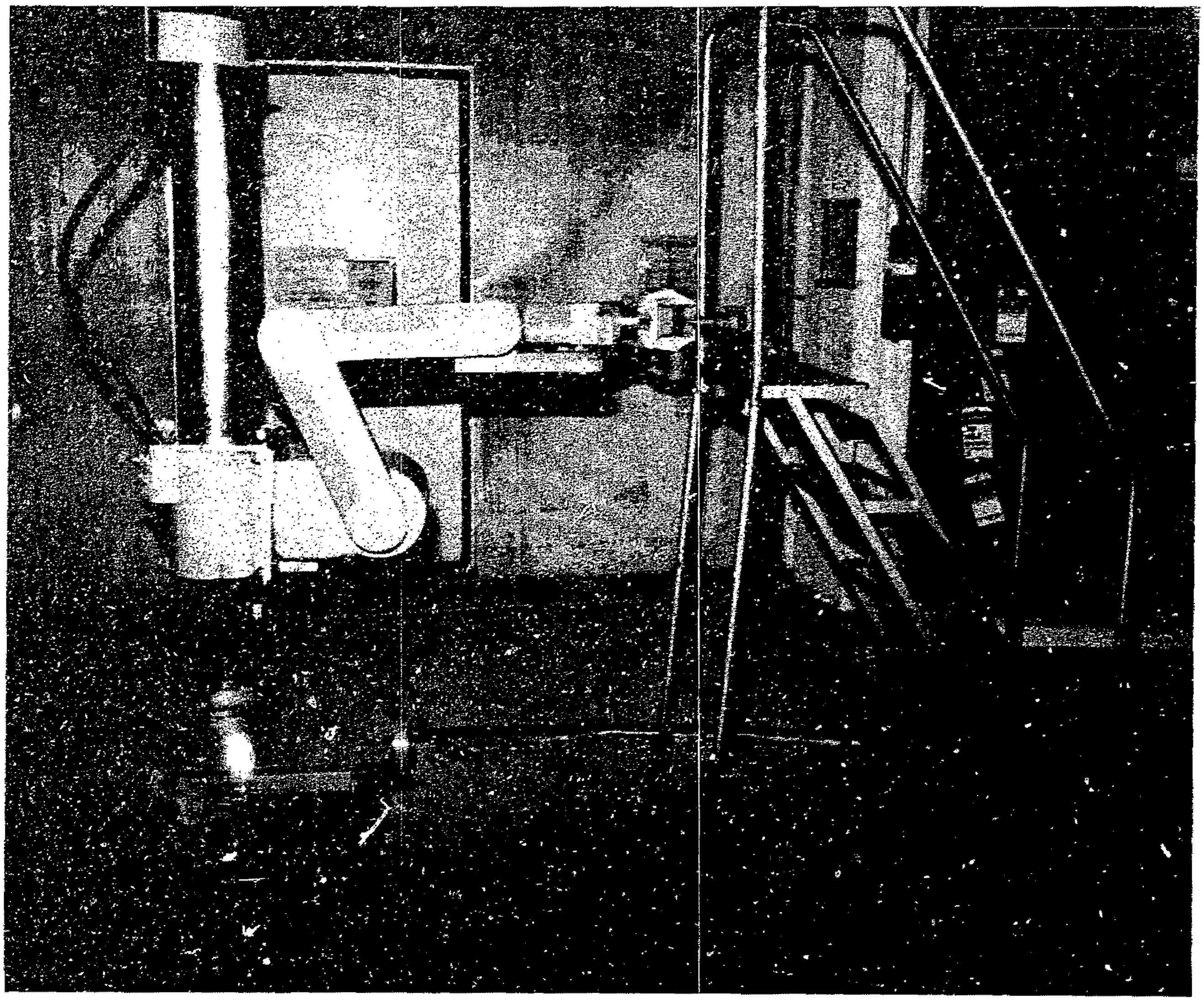


*Figure 3* **Louie's 1.3-m manipulator arm will help monitor cesium levels in a high radiation area.**

Louie's components include a transporter base, a telescoping tube, a manipulator arm, three cameras, lights, and a 30-m-long control cable. Pictured in *Figure 3*, Louie's telescoping tube and manipulator arm have a combined vertical reach of 2.9 m, which is ample height to reach nearly to the top of the 3-m-high demineralizer tanks. Its manipulator arm can reach as far as 1.3 m horizontally in any direction. Louie's strength will not be needed for its demineralizer work, but the telescoping tube can hoist up to 450 kg, and the manipulator arm can lift and maneuver up to 68 kg.

Louie's cameras are radiation hardened, and will be the operating technician's "eyes" in the cubicles, not only for positioning Louie and the gamma monitor correctly, but also for observing conditions inside the cubicles during the rinsing and elution processes. The 30-m cable connecting the transporter to the control console outside the cubicles weighs nearly 23 kg.

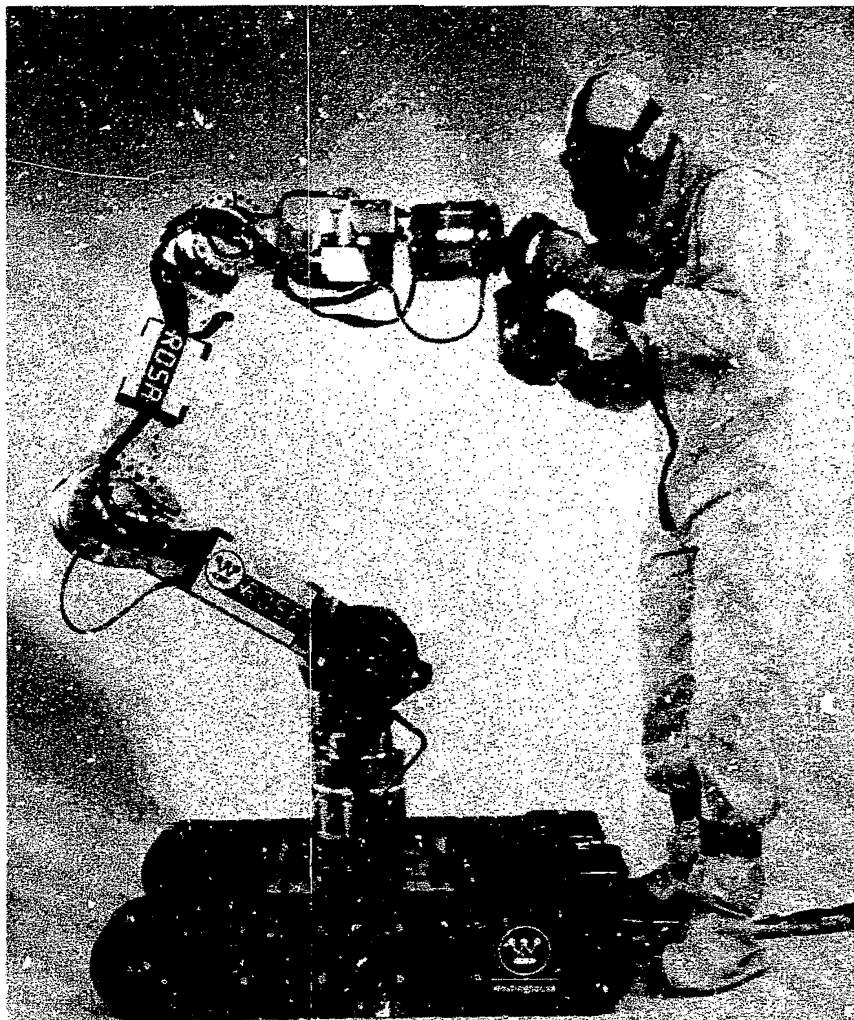
This robot is a simple one, whose every movement must be dictated by the operating technician. It has no ability to interpret commands or repeat activities on its own. Classed as a "master-slave" robot, it is basically a hot cell manipulator arm on a transporter. But its simplicity does not diminish its usefulness to the cleanup task in which it will serve. The radiation monitor Louie will carry will help determine when the $^{137}Cs$ concentrations in the demineralizer resins have been reduced to the lowest practical level. Operating technicians will conclude the rinsing and elution process when the gamma detectors show no change in readings after two consecutive elution cycles. Louie could be exposed to dose rates of up to 3000 R/h in the course of the cesium elution process. Its use will greatly reduce the human exposure risks involved in the important task of eluting and removing the purification system resins from the plant.

Robots may play a key role in the defueling of the reactor vessel, scheduled to begin in late 1986. A remotely controlled tool positioning system called ROSA might be used in place of long-handled tools handled by human workers in the Reactor Building. ROSA is a Westinghouse Electric Corporation robot; its name is an acronym for Remotely Operated Service Arm. It can be used in connection with a Westinghouse-designed defueling system to remove all debris from the damaged Unit 2 reactor.

Research has shown that the accident reduced much of the original core to a bed of rubble. The top 1.5 m of the core is now a large cavity, with a volume of approximately 9.5 $m^3$. Into this cavity, cleanup engineers will lower a variety of special equipment. Small, loose debris will be vacuumed out of the core into shipping canisters located inside the Reactor Building. Large debris will be reduced to a smaller size and then removed to shipping canisters. Material fused to the rubble bed will be cut loose with cutting shears, chisels, and drills. Items to be removed intact for research studies will be placed into debris baskets hanging inside the core. ROSA can do the lifting, rearranging, and positioning required for these special defueling activities.

Westinghouse's ROSA, shown on a transporter in *Figure 4*, is a manipulator arm with humanlike articulation at a "shoulder," "elbow," and "wrist." Its flexibility comes from its modular design. The arm consists of six segments, each of which is a self-contained unit with a motor, gear train, brake, and position indicators. Constructed of lightweight alloys, the arm is very strong for its 54-kg weight. When fully extended to its 2-m length, ROSA can lift 23 kg; when the arm is close to its base, it can lift more than 90 kg. With special adjustments, ROSA may be able to lift even more weight. ROSA's arm joints are all electric, but are completely watertight so the arm will work well in the flooded vessel and canal.

*Figure 4* **ROSA's "shoulder," "elbow," and "wrist" move to commands issued through a computer.**



A 180-m umbilical cable will connect ROSA to its control computer, to be located in a trailer outside the Reactor Building. This computer, containing several microprocessors operating in parallel, is ROSA's brain. For manual control, an operator sits at the control console, issuing commands with a joystick. The computer translates these commands into arm movements.

Unlike the movements of such master-slave robots as Louie, ROSA's movements do not need to be dictated step-by-step. The computer calculates the arm joint movements required along six different axes to move the arm in the manner indicated by the joystick. The calculations are performed in a fraction of a second, and the arm responds almost immediately.

ROSA's computer can be preprogrammed with complete instructions for any standard task. The arm can also be taught to perform a specific activity. An operator first leads ROSA through the activity with the joystick and then instructs the robot to repeat that activity, unsupervised. ROSA's memory records all the information necessary to repeat the activity indefinitely. Both the preprogramming and the teachability will be useful for repetitive, tedious tasks.

Westinghouse developed ROSA in the early 1980s and has used ROSA in steam generator repair work and inside reactor vessels. ROSA would remain the property of Westinghouse during its use at TMI. Indeed, it would be accompanied by a Westinghouse technical adviser and operated by Westinghouse technicians. But the robotic arm can far outwork its human counterparts. While they are restricted to eight-hour days, ROSA can work without rest or maintenance for 1500 nonstop hours. ROSA's flexibility, strength, and ease of operation can help to complete the defueling operation safely and efficiently.

Louie and ROSA can complete vital cleanup tasks along the road to cleanup of the TMI-2 plant. They are designed to be versatile, and each could be used for jobs not discussed here. GPU Nuclear is working with the Electric Power Research Institute and Carnegie-Mellon University to develop another robot for performing characterization and cleanup tasks, and the potential for using robots in other areas in the future continues to be examined. These machines can play a useful role in both simple and complex jobs as they help keep human exposure as low as is reasonably achievable.□

# Source Term Assessment Continues at TMI

The TI&EP continues to make progress in its studies of source term, recently completing visual inspections of the TMI-2 Reactor Coolant Drain Tank (RCDT) and investigating the concentration of radioiodine and tellurium in the reactor core and building basement. In a related effort, GPU Nuclear engineers took concrete core samples on the 305-ft and 347-ft elevations to assess radionuclide penetration into the concrete.

The RCDT was the major pathway for the release of accident water into the Reactor Building basement. In video inspections of the tank below the vent line, analysts saw a dark, particulate sediment of less than 0.32 cm thick, nonuniformly distributed on the bottom. Personnel also saw particles larger than they predicted would have been released through the pressurizer to the drain tank; they calculated a maximum particle size of 30 $\mu$m.

During each of these inspections, samples of the water and sediment were extracted for analysis. By studying the samples, personnel at the Idaho National Engineering Laboratory (INEL) will determine the quantity of fuel and fission products released to the RCDT. The resulting data will also support ongoing analyses of fission product mass balance and source term—the concentration and distribution of radionuclide activity.

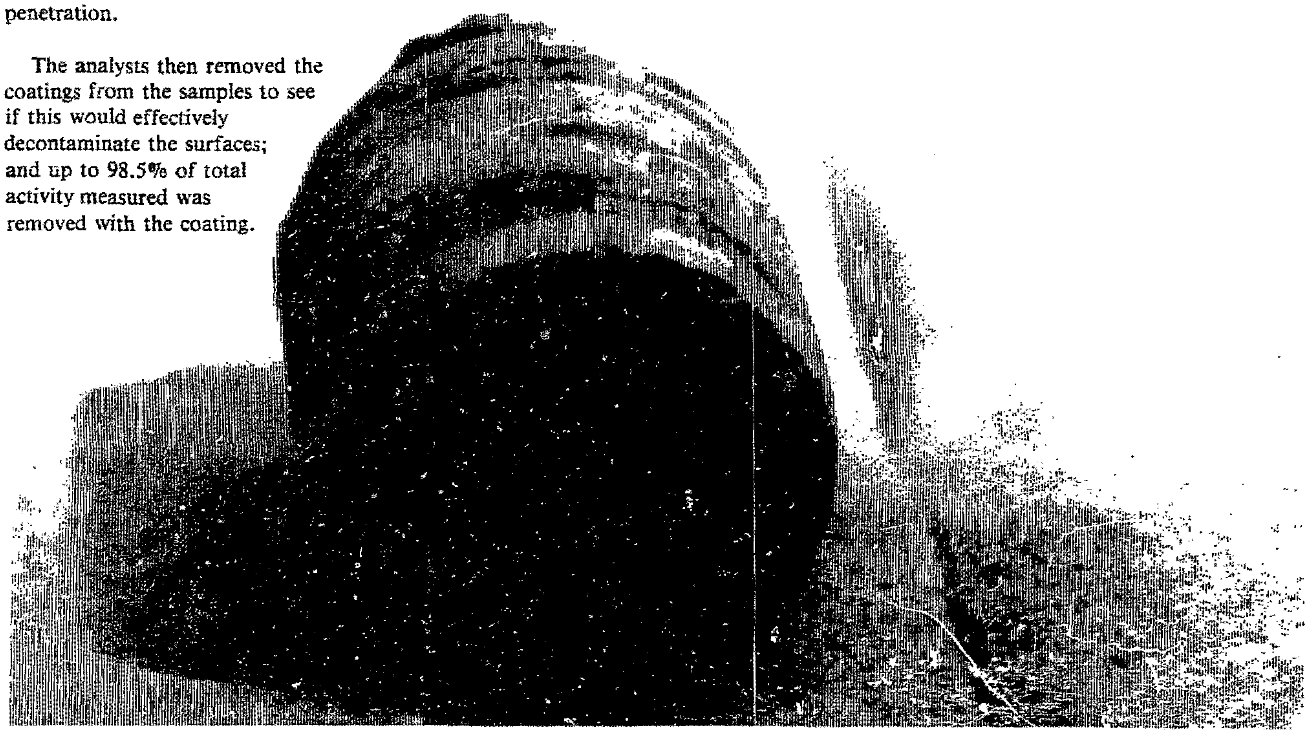
In defining the source term in Unit 2, program personnel are placing special emphasis on determining the concentration of $^{129}$I and $^{130}$Te in liquid and solid samples collected from the reactor core and Reactor Building basement. Data collected to date indicate that the fraction of radioiodine released from the core to the basement is significantly less than the fraction of radiocesium released to the basement. Basement sediment samples are being analyzed to determine if the radioiodine precipitated. Lead screw and core grab samples are being analyzed for $^{130}$Te—whose behavior is important because it is a parent of iodine—to determine if plateout or scavenging of the tellurium significantly reduced the amount of radioiodine released from the core.

To assess the extent to which radionuclides migrated into the concrete in the building, engineers obtained 17 samples of concrete from the 305-ft and 347-ft elevations. (The basement concrete was not included in this study because of its inaccessibility.) Tests on these large core samples, obtained using a concrete boring tool, resulted in one significant finding: that the majority of radionuclides released from the Reactor Coolant System (RCS) into the Reactor Building environment were trapped in the concrete's surface coatings.

Most concrete surfaces in TMI-2 are protected with epoxy-based, nuclear-grade coatings, making an otherwise porous concrete resistant and easier to decontaminate. Pictured in *Figure 5* is a sample of concrete taken from the D ring wall at the 305-ft elevation. To its right is the sample's autoradiograph, which documents the coating's ability to absorb radionuclides and prevent them from penetrating the concrete. Only where the coating was scarred and the unprotected surface was exposed to contaminated water for an extended period of time did analysts discover significant radionuclide penetration.

The analysts then removed the coatings from the samples to see if this would effectively decontaminate the surfaces; and up to 98.5% of total activity measured was removed with the coating.

While analysts are not saying widespread coating removal in TMI-2 is necessary, it may be beneficial in areas where long-term personnel operations are planned. A GPU Nuclear report suggests devising other equally effective decontamination methods as alternatives to coating removal. □



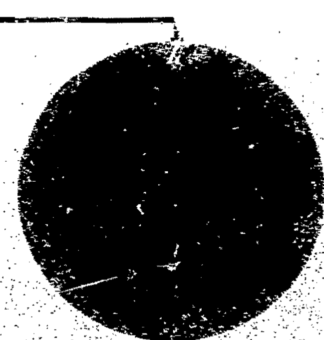



*Figure 5* **This concrete core sample, whose coating was accidentally chipped during removal, was taken from the D ring wall at the 305-ft elevation. Its autoradiograph, at right, shows dark shading where the coating protected the concrete from radionuclide penetration.**

# Hydrogen Burn Study Answers Questions About Its Cause and Damage

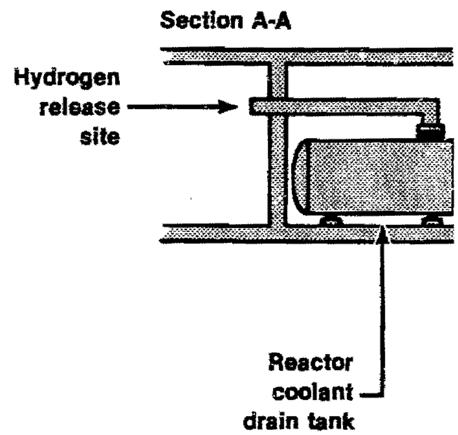
After two years of research and analysis, TI&EP engineers completed their studies of the hydrogen burn that occurred at TMI, answering a number of questions generated from the event and gaining a better understanding of its cause and its damage.

Overall, analysts concluded that the hydrogen burn caused little damage to the Reactor Building itself and no damage to safety systems. The damage that was found, for the most part, was fully consistent with TI&EP expectations.

The burn occurred about 10 hours into the accident, after the reactor core overheated and the zircaloy cladding that encased the fuel reacted with steam, liberating large quantities of hydrogen to the building, where the gas later ignited. The estimated pressure rise time for the event was 10 to 15 seconds, but most of the 28-psig pressure increase occurred in the final 3 to 6 seconds.

Evidence, such as charred paint and cables, indicates a flame rose from the building basement to the dome, where it remained until quenched.

The precise location and ignition source of the flame are unknown and may always be so, but evidence indicates the burn originated on the building's west side, in the basement. Among the candidate sources of the burn is the electrical equipment on two Motor Control Centers that tripped at the time of the event. Access to the 282-ft level will provide further insight into the ignition source and location.




Location of hydrogen release

Calculations by several researchers indicate that about 370 kg of hydrogen were in the Reactor Building at ignition, of which about 320 kg burned. A hydrogen and steam mixture was released into the building through the discharge duct from the RCDT, as illustrated in *Figure 6*. The hydrogen then rose through openings and became well mixed throughout most of the building by way of the ventilation system, with an average concentration being 7 to 8%, depending on water vapor concentrations. Somewhat leaner hydrogen concentrations existed in the unventilated enclosed stairwell and elevator hoistway, while richer concentrations existed immediately before the burn in the vicinity of the release site and open stairway.

Since the electrical equipment was operating in the presence of a flammable mixture for one to seven hours, analysts questioned why ignition did not occur earlier. They developed three possible explanations. First, releases of steam early in the accident generated relatively high concentrations of water vapor, thus raising the lower flammability limit of hydrogen in air. Second, sparks occurring earlier may have been too weak to cause an ignition. And third, it is possible that earlier ignitions did actually occur, but without any significant flame propagation away from the ignition site.

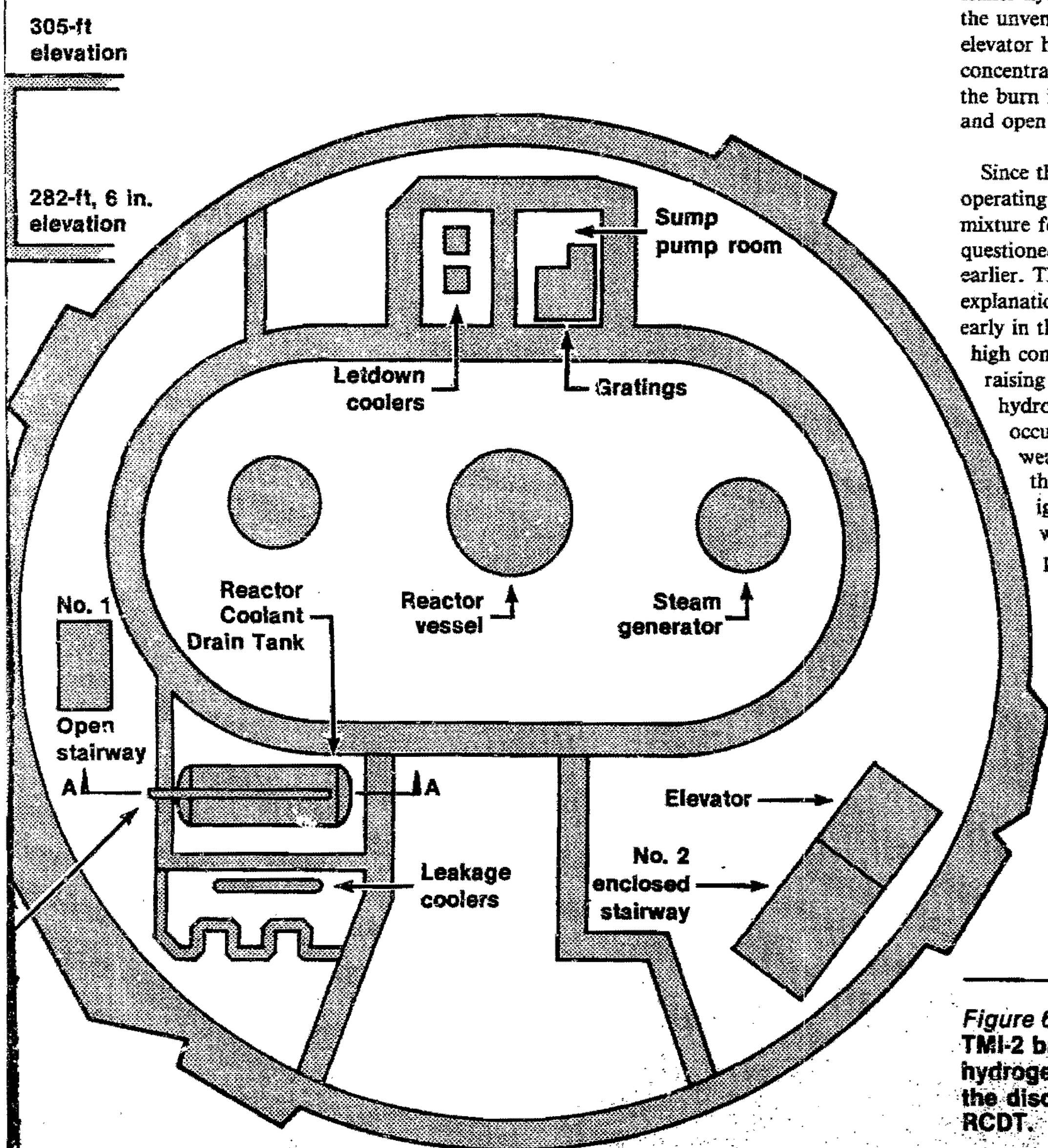
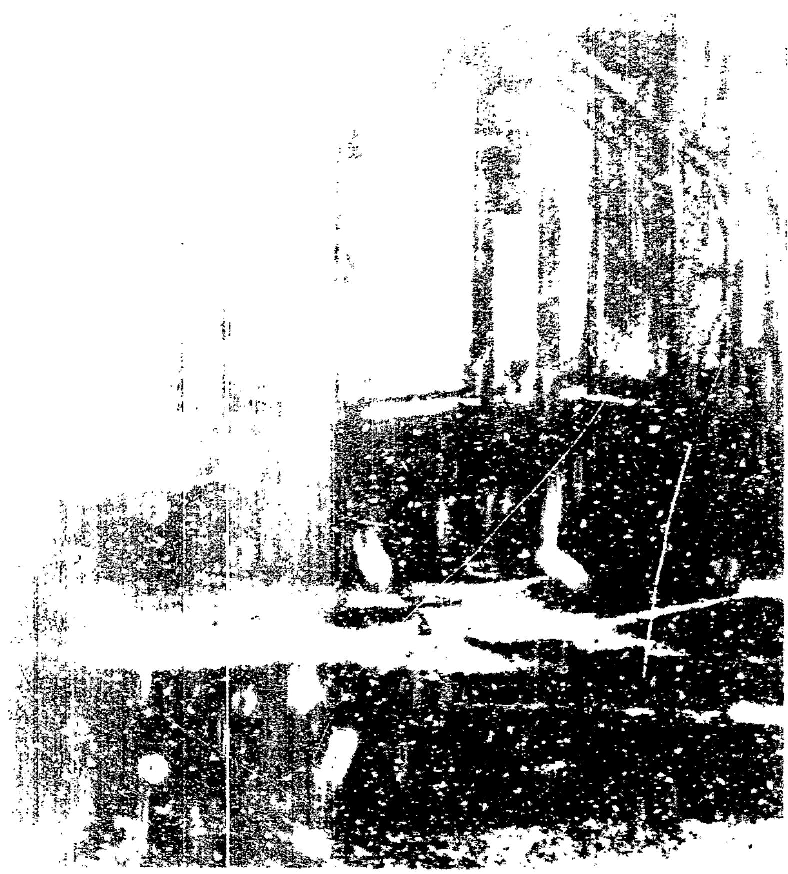



*Figure 6* **As this drawing of the TMI-2 basement indicates, the hydrogen was released through the discharge duct from the RCDT.**



# TMI Program Highlights Available on Videotape

The TI&EP has released a videotape program for loan without charge. "1983 in Review: A DOE TMI-2 Programs Brief" is a 16-minute program highlighting the accomplishments of 1983 at TMI. The program covers the shipment of the last processing container used to decontaminate accident water, experiments to immobilize the contaminated contents of this and other containers, the study of the hydrogen burn event, tests to determine cable and connection performance in accident and postaccident environments, sampling of the rubble bed in the core, and fabrication of a clear plastic model of the cavity in the damaged reactor, among other achievements.

This videotape may be obtained by contacting Kim Haddock, EG&G Idaho, Inc., TMI Site Office, P.O. Box 88, Middletown, PA 17057, telephone FTS 590-1019 or (717) 948-1019.

# DOE Studies of Ion Exchange Media Focus on Gas Generation and Resin Degradation

Through DOE research into the accident at TMI, laboratory personnel have learned a great deal about organic and inorganic ion exchange media, both of which have been part of the cleanup process there. Researchers analyzed the media in the EPICOR II prefilters, Makeup and Purification System demineralizers, and Submerged Demineralizer System (SDS) liners, focusing specifically on two major concerns: radiolytic generation of combustible gases and resin degradation.

Organic ion exchange resins were used alone or in combination with inorganic zeolites in the 50 EPICOR II prefilters that decontaminated accident water from the Auxiliary and Fuel Handling buildings. Research on the EPICOR II ion exchange media focused specifically on radiolytic generation of combustible gases, resin degradation, and liner integrity. Laboratory scale studies have shown that at doses of about $10^7$ rads and more, residual water in the organic resin decomposes and the resin itself degrades. Both processes generate gases which could lead to combustible gas mixtures in containers during handling, shipping, or storage.

The radiolytic decomposition of water produces hydrogen, which accumulates in sealed containers, and oxygen, which is consumed during a reaction with the organic resin and water in the container. The hydrogen gas generation rate is dependent on the radiation dose to the water and organic resin: the rate increases in a nearly linear relationship with an increasing curie content *(see Figure 8)*. Internal pressure in a sealed container will at first decrease sharply as oxygen in the air inside the container is consumed by a chemical reaction. The dose delivered to the organic resin acts as a catalyst for this reaction. When all the oxygen has reacted, the ongoing radiolytic process builds up hydrogen gas concentrations in the container, causing an increase in container pressure above atmospheric pressure.

At TMI, potential hazards associated with this hydrogen gas buildup in sealed containers led DOE researchers to develop a tool to solve the problem. A gas sampler with a remotely operated support facility safely vented, sampled, and purged gases in waste containers. The remote operation reduced both man-rem exposure and potential hazards associated with hydrogen gas.

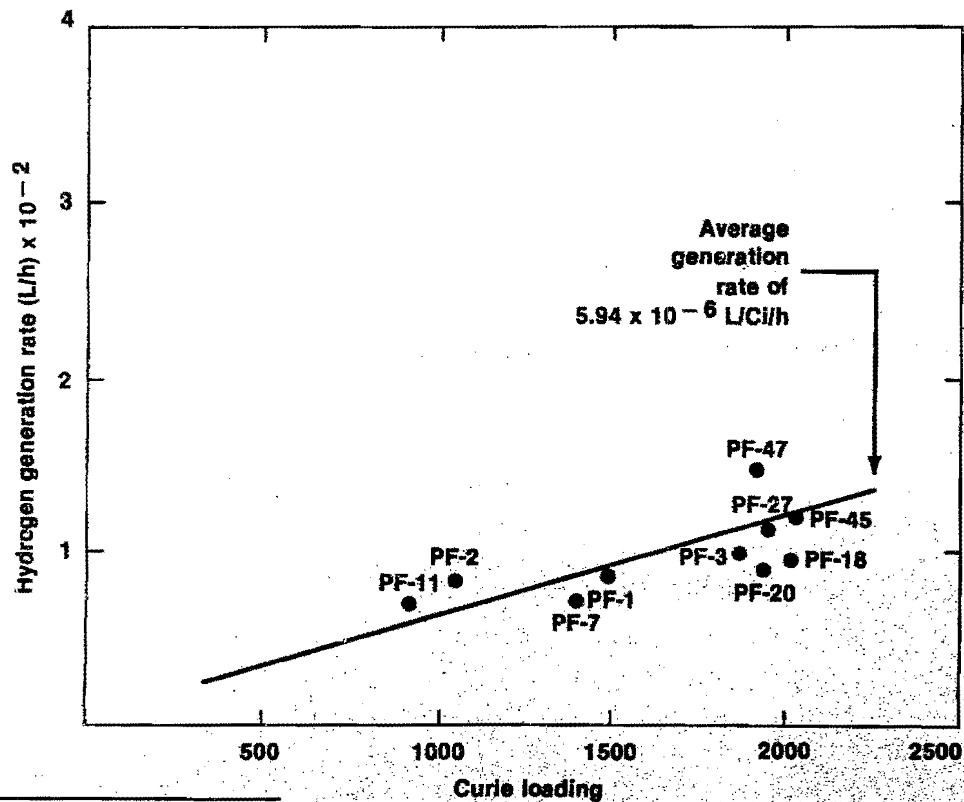



*Figure 8* **This graph presents hydrogen generation rates versus curies for EPICOR II prefilters.**

In a closer look at resin degradation, analysts characterized the two worst-case EPICOR II prefilters and found that the pH of the ion exchange media was acidic and became significantly more so from top to bottom of the bed. But resin degradation, such as surface cracking, spalling, and fragmentation due to radiation exposure appeared to be minimal. This minimal degradation was observed at the bottom of the bed, far from the highest activity loading. Thus, it likely was the result of high moisture content or chemical attack. Analyses also demonstrate no significant leaching of nuclides from the resin and essentially no threat to liner integrity. And results of metallurgical studies suggest that the liners can be disposed of safely for more than 300 years in high-integrity containers without any threat to the environment.

Studying the two Makeup and Purification System demineralizers, analysts focused on resin degradation due to irradiation and high temperatures. After five years of radioactive decay, demineralizer A contains approximately 5000 Ci of cesium, and demineralizer B holds about 14,000 Ci of cesium. To date, these resins have absorbed a dose of more than $10^9$ rads. In addition, fission product decay heat likely produced temperatures of up to 811 K. As expected, this combination of high temperatures and radiation dose caused the demineralizer resins to degrade; the bed size reduced by about 70%.

Samples of both demineralizer beds were sent to Oak Ridge National Laboratory for analysis. Demineralizer A was found to be dry, with agglomerated, black resin fragments, indicating temperatures in excess of 672 K and extensive radiation damage. Analysts have not concluded whether this vessel's resins are sluicible, but they have confirmed that demineralizer B resins likely can be sluiced because they remained under water.

As expected in resins irradiated to the high levels found in these two vessels, radiolysis produced hydrogen and oxygen gases. Analysts say the hydrogen generation and oxygen depletion mechanisms observed in these resins were the same as in the EPICOR II system ion exchange media. Before sluicing, the cesium will be removed by elution from the resins and processed by the SDS zeolites, whose abilities to handle such high curie loadings has been proven.

SDS was the third system at TMI in which an ion exchange medium was used. The inorganic zeolites in these liners effectively processed about 3785 $m^3$ of contaminated water from the reactor coolant bleed tanks, the RCS, and the building basement.

Below a dose of $10^9$ rads, inorganic zeolites do not suffer radiation degradation; the only effect of the extremely high curie loading is radiolytic generation of hydrogen and oxygen gases. Focusing their studies on this concern, analysts have found that gas generation rates are approximately proportional to curie loading. Also, the oxygen depletion mechanism found in organic resins does not occur with inorganic zeolites to the same degree. The measured fraction of hydrogen was greater than stoichiometric, but oxygen was generated in sufficient quantities to form a combustible mixture in a sealed container.

Zeolite liners in storage at TMI exhibited gas generation rates of nearly 1 L/h. Rockwell Hanford Operations developed a catalyst recombiner and vacuum outgassing system to solve the gas generation problem. Vacuum outgassing removed residual water, and palladium catalyst pellets recombined the radiolytic gases generated from both the residual and chemically bound water so the liners could be safely shipped from the Island. □

# Core Topography System Data and Photos Give First Accurate Picture of Core Void

As reported in the December 15, 1983, issue of the *Update*, engineers lowered a sonic sensing head into the TMI-2 core and collected nearly 500,000 data points to acoustically map the size and shape of the cavity inside the damaged reactor.

Since then, these individual data points have been reconstructed into the three-dimensional clear plastic model pictured in *Figure 9*. This model is the first accurate map of the upper portion of the core, which experienced considerable damage during the accident.

The model shows in some places the void extends all the way to the edge of the core. The suspended materials in the model are axial power shaping rods, which were driven in after the accident, and stubs of fuel assemblies. After studying the results of the core topography system, engineers have determined the cavity volume to be approximately 9.5 $m^3$. At the deepest point, the cavity drops about 2 m, as measured from the underside of the plenum.

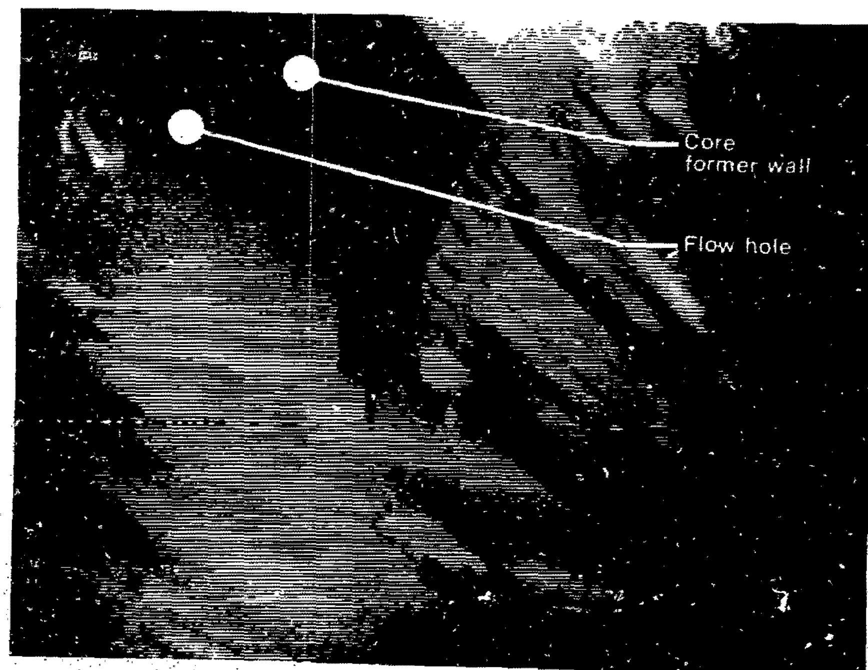
***Figure 9*** **Mike Martin, senior project engineer, explains the making of this clear plastic model of the core void, developed from nearly 500,000 data points.**

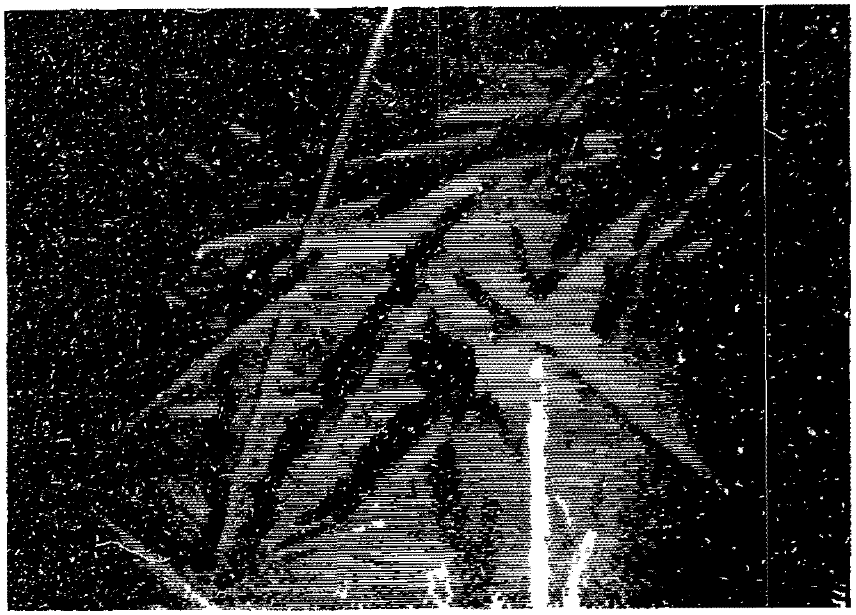
These findings are also supported by videotapes of the region between the plenum and rubble bed. *Figure 10* shows the stubs of fuel assemblies hanging unsupported from the underside of the reactor plenum. Data from the sonar mapping device indicate these segments typically are 5 to 25 cm long. A close shot, seen in *Figure 11*, reveals an exposed fuel rod plenum spring. In *Figure 12*, the core former wall is clearly visible and appears in most places to be undamaged. Just in one area on the east side of the reactor does the core former wall appear to bow outward by about 6 cm.

***Figure 10* Stubs of fuel assemblies hang from the underside of the plenum assembly.**


*Figure 11* **This fuel rod broke off close to the end fitting, exposing the fuel rod plenum spring.**

*Figure 12* **Although the void extends, in most places, to the edge of the core, the core former wall appears undamaged.**





Only the top 1.5 m of the nearly 4-m-tall core are visible to analysts at this time; the area below is still unknown. But looking down, the video camera has provided some clear photographs of the rubble bed. In *Figure 13*, fractured fuel rods lay like pickup sticks on the surface of the gravel-like rubble bed. Fuel rod plenum springs are also visible there *(see Figure 14)*. And contrary to earlier conclusions based on limited visual observations, the surface of the rubble bed is uneven. In one region of the rubble bed, engineers saw a "valley," which they speculate was created during the accident by upward water flowing through the rubble bed.

*Figure 13* **Fractured fuel rods lie scattered across the surface of the rubble bed.**

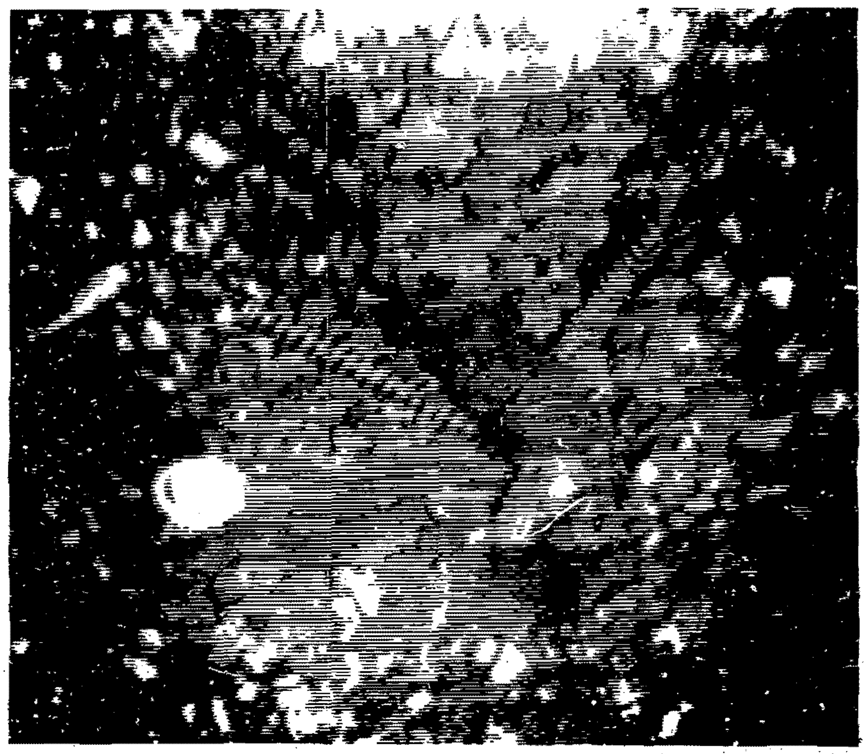


*Figure 14* **In a closer shot, fuel rod plenum springs are also visible on the rubble bed surface.**

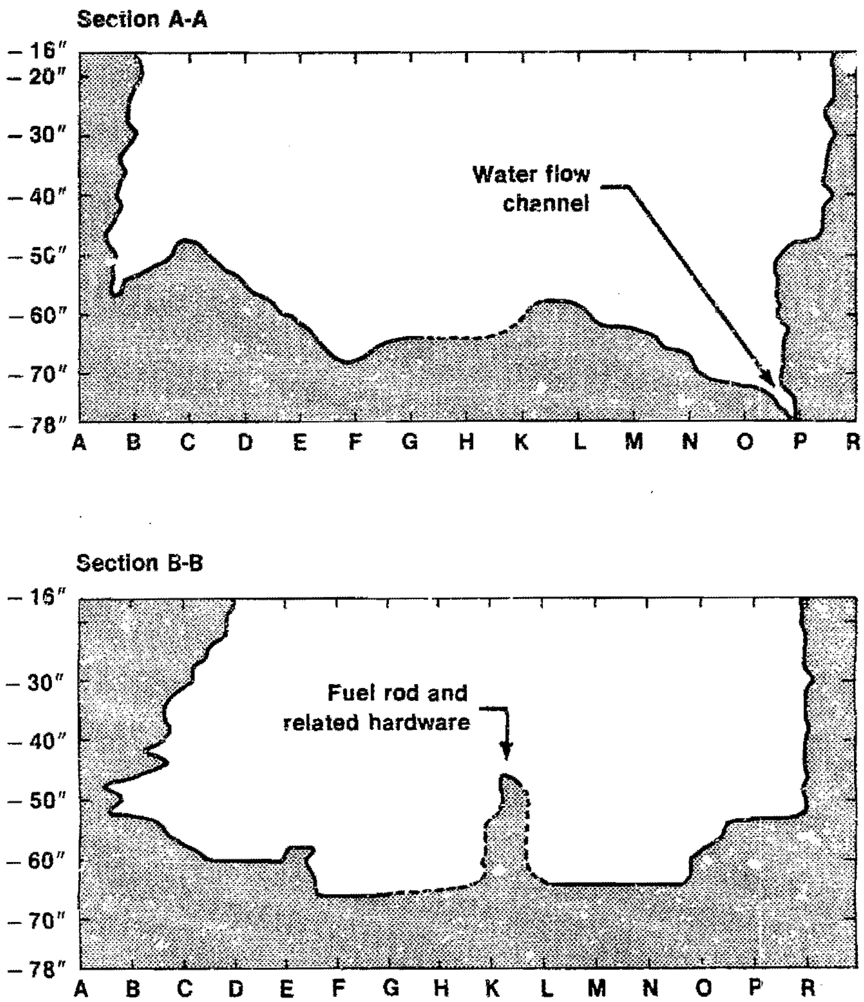



*Figure 15* **Sections A-A and B-B are topographical plot cross sections of the TMI-2 core void.**

Using the data collected from the sonic sensing head, engineers also were able to plot cross sections of the void. Two such cross sections are presented in *Figure 15*. The solid lines in these drawings were produced from actual data, while the dashed lines are approximate locations obtained by extrapolation or interpolation. (A few areas of the rubble bed were not within the range of the acoustic transducers.)

Section A-A of *Figure 15* shows the deepest point of the void, at Position P, where water possibly flowed, as explained earlier. The bottom of this narrow channel is about 2 m into the core. In Section B-B, the data points plotted in the center of the cross section jut up into the void. As videotapes of this region confirm, this protrusion is a partial fuel rod and its associated hardware, which fell from the plenum into the rubble bed.

As a result of this information, analysts have concluded that 135 of the total 177 fuel assemblies in Unit 2 are broken, thus creating the void in the top 1.5 m of the core. Of the remaining 42 assemblies, 19 are more than 50% intact (including the two possible fully intact assemblies), and 23 are less than 50% intact. Again, these numbers strictly pertain to the known 1.5 m of the core. This and other sonar topographic data are still being evaluated and will be useful in planning for plenum and fuel removal.

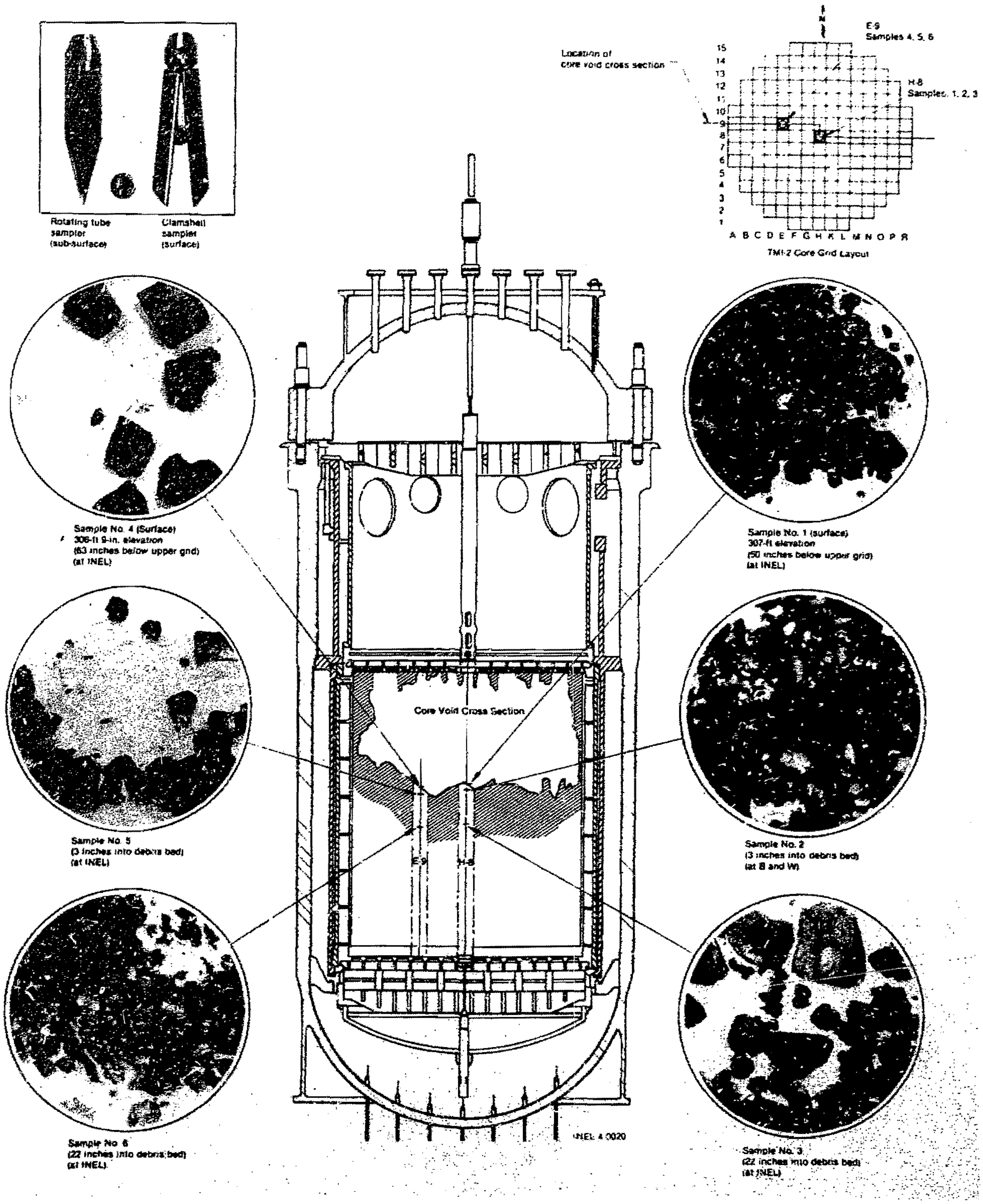
Engineers plan this year to answer some questions about the unknown region below the currently defined void by analyzing more samples taken from deep in the rubble bed.□

# First Samples of Core Debris Analyzed

These six samples shown at right were the first obtained from the damaged TMI-2 reactor core. After their removal last fall, five of the samples were sent to the INEL and the sixth to Babcock & Wilcox laboratories in Lynchburg, Virginia, where they were weighed and photographed.

At the INEL, analysts removed eight particles from the five samples for gamma spectroscopy and fissile determination. The core debris consisted of fuel pellet fragments, shards of cladding or guide tubes, and particles which appear to be glazed with previously liquid material. Five of the eight particles were primarily fuel. While $^{144}Ce$, $^{106}Ru$, and $^{154}Eu$ appeared to be associated mostly with the fuel, $^{137}Cs$ and $^{125}Sb$ were released from the fuel particles. Based on a limited analysis, the released cesium and antimony appear to be present on other core materials. Radiation levels for the five samples, using a teletector from 2.5 cm away, ranged from 3 to 36 R/h gamma. Particle sizes ranged from about 0.6 cm to a fine debris. One surface sample consisted of 13 large chunks of material.

Future work will address the chemistry of the debris in all six samples. The information from the debris samples will aid in assessing the tools and procedures required to defuel the TMI-2 reactor. In addition, the data will be used to define the behavior of a commercial reactor core under the accident conditions found in TMI-2. □


Rotating tube sampler (sub-surface)
Clamshell sampler (surface)
Location of core void cross section
E-9 Samples 4, 5, 6
H-8 Samples 1, 2, 3
A B C D E F G H K L M N O P R
TMI-2 Core Grid Layout
Sample No. 4 (Surface) 306-ft 9-in. elevation (63 inches below upper grid) (at INEL)
Sample No. 1 (surface) 307-ft elevation (50 inches below upper grid) (at INEL)
Core Void Cross Section
Sample No. 5 (3 inches into debris bed) (at INEL)
Sample No. 2 (3 inches into debris bed) (at B and W)
E-9
H-8
Sample No. 6 (22 inches into debris bed) (at INEL)
Sample No. 3 (22 inches into debris bed) (at INEL)
INEL 4 0020

# TMI-2 Topics

**In the TMI-2 Topics**, you will read news items of interest to the nuclear power industry which may not cover work conducted under the auspices of the DOE TI&EP. The TI&EP Information and Industry Coordination group transmits such news items at technical meetings, and through the Nuclear Operations and Maintenance Information Services (NOMIS). For more information, contact John Saunders or Jim Flaherty, TI&EP Information and Industry Coordination, FTS 590-1063 or (717) 948-1063.

**TEST PROVES CRANE CAN LIFT VESSEL HEAD**

The Unit 2 polar crane successfully passed a load lifting test on February 29 when it lifted and maneuvered a 214-ton load in the Reactor Building. The load test indicates the crane can safely lift and remove the 170-ton reactor vessel head. The polar crane was damaged as a result of the 1979 accident and underwent nearly a year of inspections and repairs. Engineers first tested the crane without a load to assess its structural integrity and its mechanical and electrical functions. The load test was delayed one year because of concerns about the safety and feasibility of the test. The Nuclear Regulatory Commission investigated the safety of the test and concluded in November 1983 that it could be conducted without risk.

The crane stacked four 40-ton missile shields from over the reactor vessel and one 32-ton missile shield from over the reactor system pressurizer into a steel lifting frame. This stack, together with the lifting frame and assorted rigging assemblies, constituted the test load. The load was lifted, lowered, stopped and held by the hoist brakes, and then lowered to the floor. Then the load was transported 3 m out and back by the crane trolley and approximately 3 m from side to side by the crane bridge. The bridge was rotated 180 degrees and the load was lifted again. As a result of the load test, the polar crane will be rated capable of safely lifting and removing the reactor vessel head, a major step on the road to completing the cleanup.

**NEW TLDs HANDLE BETA FIELDS**

DOE TMI programs working with Pacific Northwest Laboratory have developed a multielement thermoluminescent dosimeter (TLD) capable of correcting for energy distribution in beta radiation fields. These devices have been used in the TMI recovery program to characterize beta and gamma fields in the Reactor Building while minimizing worker exposure to ionizing radiation. This new TLD system may aid the industry in [illegible] protection, and [illegible] [illegible] of safety.

## MONITORS MAY NOT BE SUITABLE FOR REACTOR BUILDING USE

Investigations of failed radiation monitors at TMI-2 have revealed that the causes of failure are not unique to an accident environment. Failures experienced by monitors at TMI could occur in similar nonqualified monitors in operating plants, indicating that these monitors may not be suitable for reactor building use.

Incorrect installation instructions supplied by vendors and installation problems are among the factors associated with radiation monitor failure at TMI. Investigations of one monitor revealed that the cable connector attaching the cable to the monitor was not screwed on properly. This improper seal allowed water to enter the connector and accumulate on the connector pins, causing a short circuit. The situation was aggravated by the fact that the entire monitor was installed upside down. Ambiguous instructions in the manufacturer's installation manual led technicians to install the monitor with the cable connection facing the ceiling. The manufacturer has since corrected the manual.

The manufacturer advises against subjecting monitors to pressures greater than 30 psig. During standard reactor building integrated leak rate tests, sealed equipment can experience differential pressures as high as 69 psig. Consequently, TMI-2 monitors had to be removed from the building during each integrated leak rate test. This only increased wear-and-tear on the instruments and the potential for installation mistakes.

Investigations have also shown that radiation monitors with connecting cables longer than 152 m can fail at radiation levels as low as 500 mR/h. The failure mode, called a foldover effect, causes control room ratemeters to show decreasing radiation levels, when in fact the levels in the plant may be increasing. The foldover is caused by a normally inconsequential impedance mismatch along the cable connecting the monitor to the ratemeter. As radiation levels increase, the instrument circuit operates at a higher frequency and the mismatch is amplified, causing a faulty drop in the ratemeter readout.

The foldover effect is amplified by another factor associated with failure of radiation monitors. Monitor components called metal oxide silicon transistors are known to degrade with accumulated radiation exposure. The TMI studies reveal that their degradation also compounds the foldover effect.

All TMI-2 studies indicate that these monitors may not be suitable for use in a reactor building. While the monitors perform satisfactorily in support building environments, they are subject to failure in the harsh environments which can be encountered in reactor buildings. □

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# UPDATE

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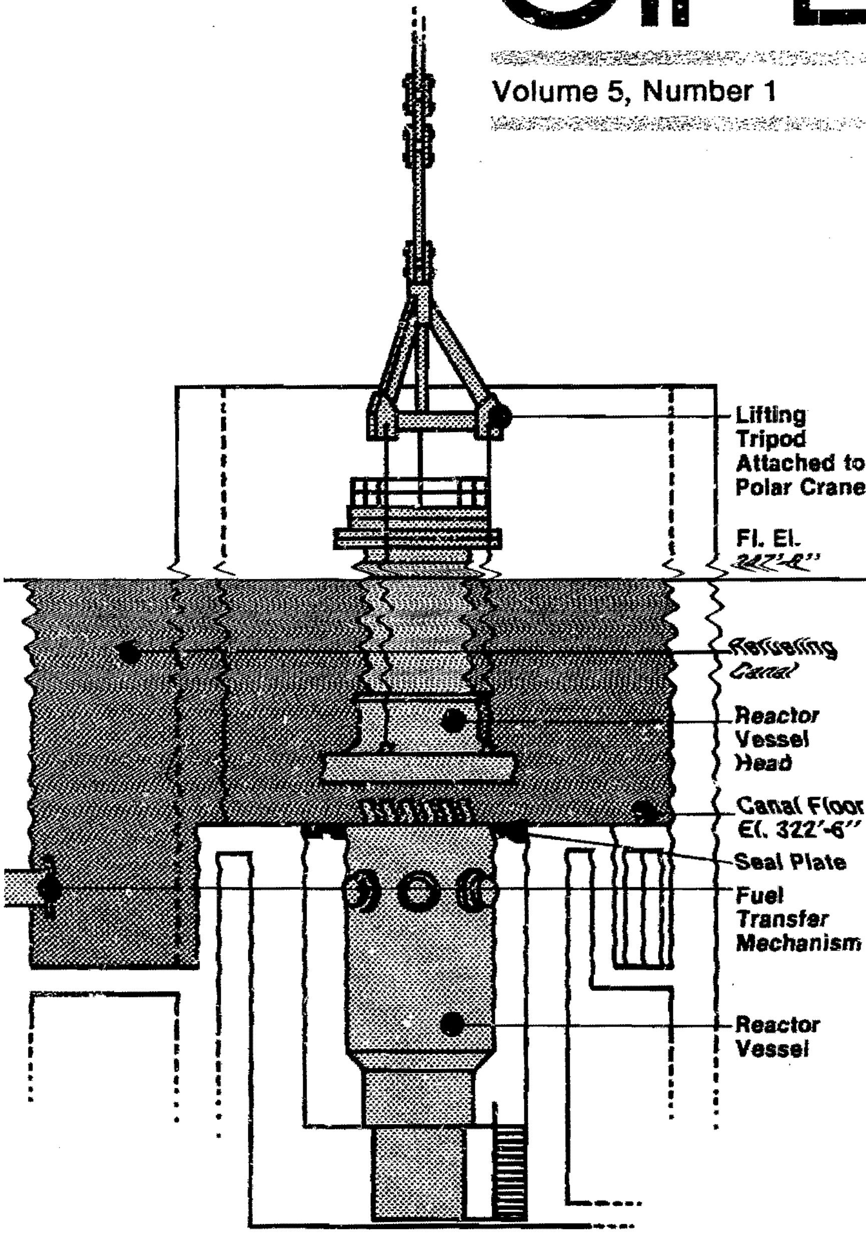
TMI Unit 2 Technical Information & Examination Program

# UPDATE

Volume 5, Number 1 November 1984




## TMI-2 Head Safely Lifted

Two teams of more than 40 workers labored around-the-clock to successfully lift the head from the damaged Three [illegible] The completion of this stage in the cleanup effort provides ready access to the internal components and fuel of the Unit 2 reactor.

The head was lifted on the evening of July 24 and was seated on its storage stand shortly after midnight the next day. The head, including the service structure, lead blanketed shielding, and lift rigging, weighs approximately 159 tons. The head consists of two major components: the domed cap of the reactor vessel and the head service structure (see Figure 1).

*Figure 1.* **Section view of reactor vessel head removal.**

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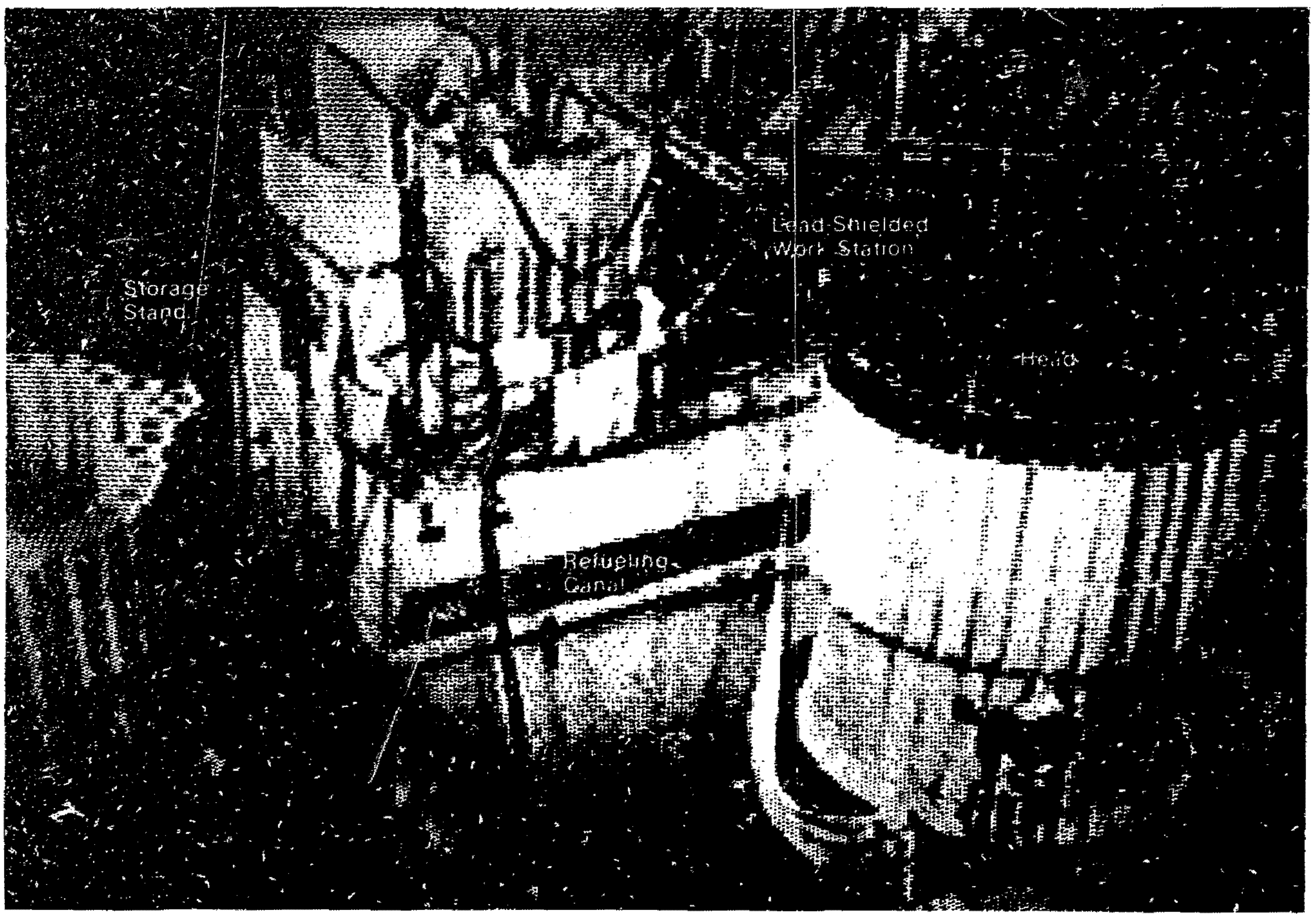


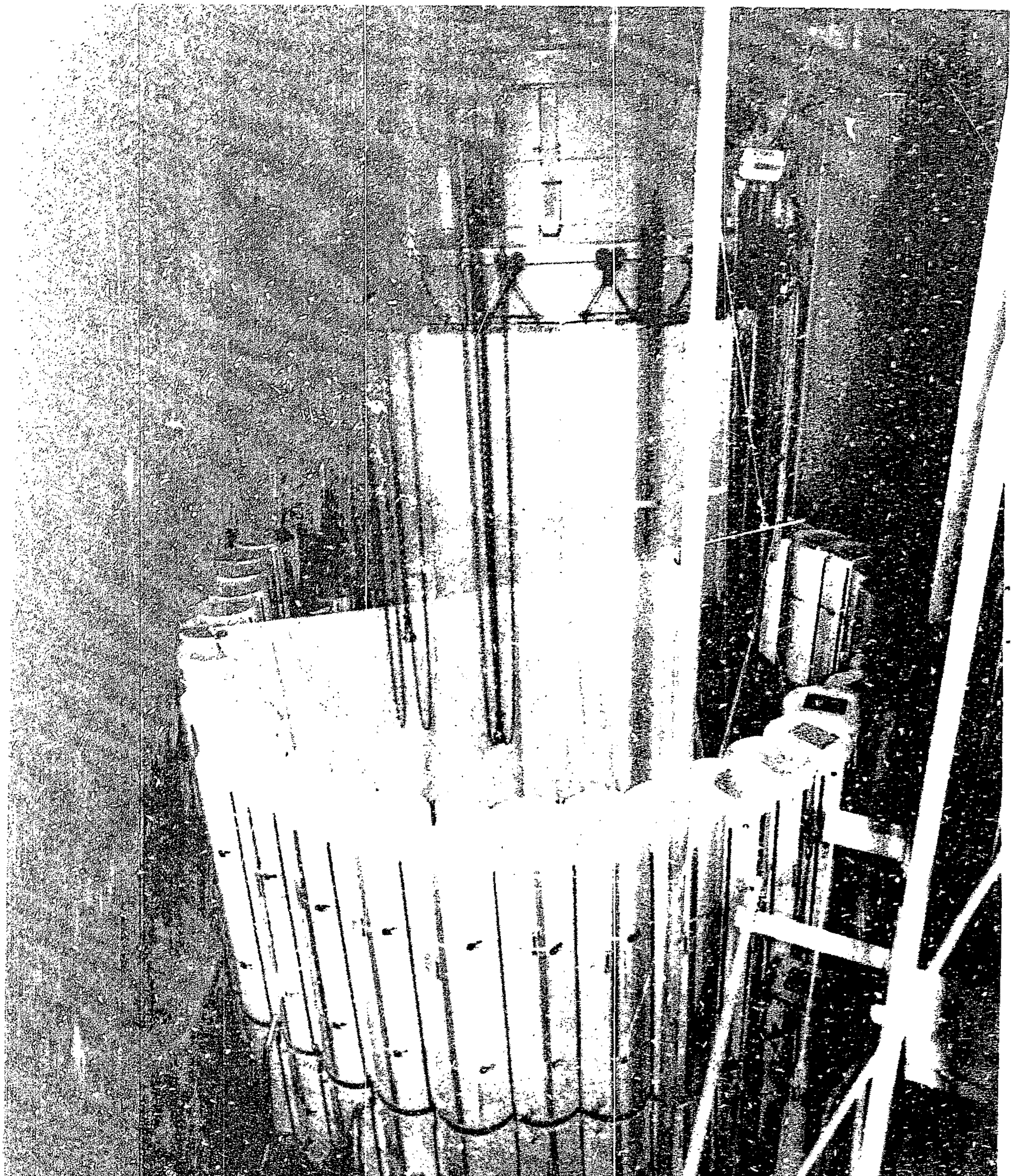

*Figure 2.* **Photo taken from television monitor of the head traveling toward the head storage stand.**

Attached to the polar crane with three cables and lifting tripod, and covered with 13 tons of lead blankets, the head was first lifted a fraction of an inch so that workers could ensure that the head was level. With the head then raised 3 feet above the reactor vessel, workers wrapped a plastic "diaper" underneath to prevent contaminants there from being spread during travel. Moving at a rate of 1 to 2 feet per minute, the head was raised 38 feet and then moved south and east towards its storage stand (see Figure 2).

During the entire process, engineers and technicians were located in a command center in the TMI-2 Turbine Building and monitored the head lift activities by closed-circuit television and mobile radio. The workers inside the Reactor Building worked most of the time inside a lead-shielded work station to minimize exposure. The Reactor Building was isolated during the lift, and radiation monitors placed inside the building showed no radiation releases during the entire operation.

The final lowering of the head was delayed while the guide holes in the head were aligned with the guide pins on the storage stand. Surrounding the head storage stand are 12-foot-high columns filled with sand that act as radiation shields. The columns were originally filled with water but were drained and refilled with sand because of leakage. Figure 3 shows the head seated on the storage stand.

*Figure 3.* **Reactor vessel head seated on storage stand.**



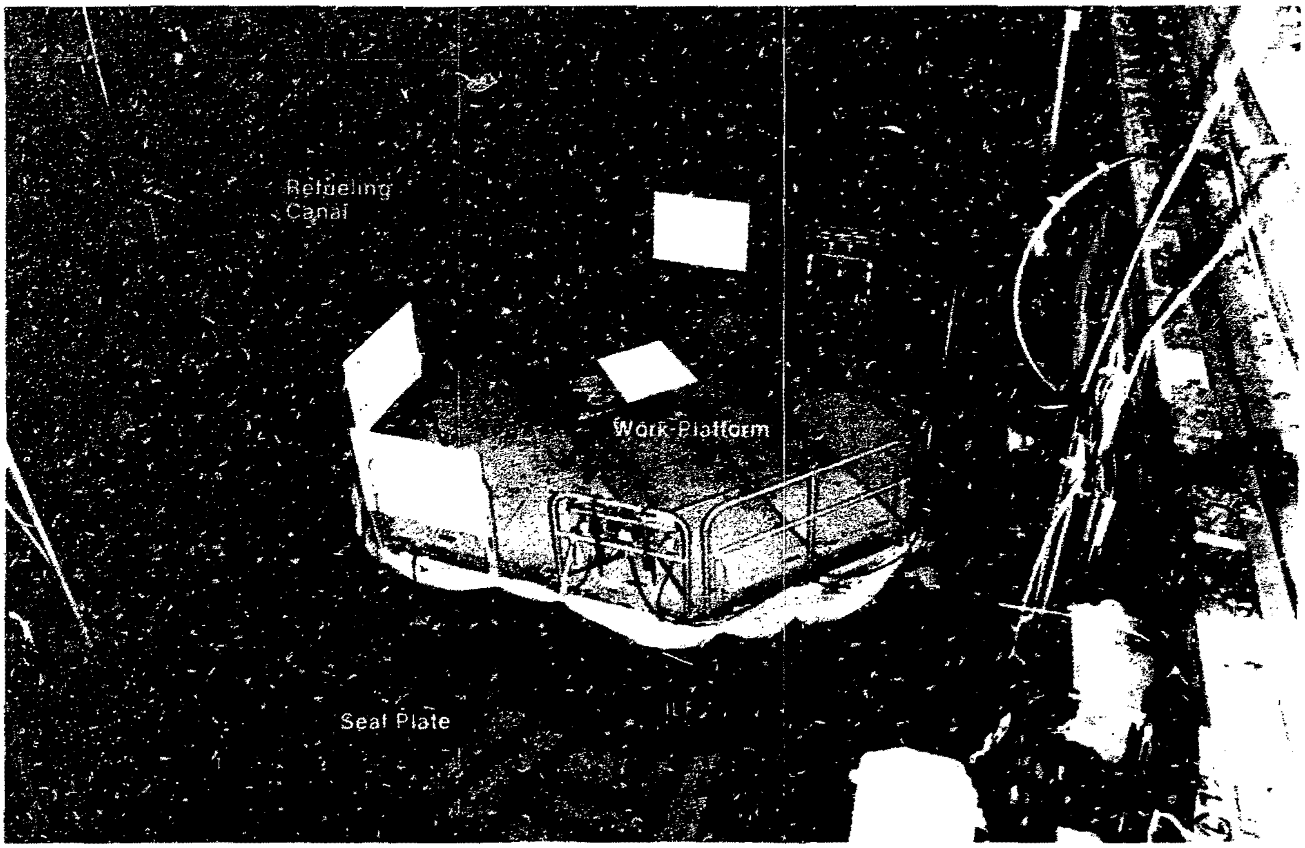



*Figure 4.* **IIF and work platform in place on the reactor vessel.**

After the head was successfully landed on the storage stand, workers released the lifting rig and attached it to the Internals Indexing Fixture (IIF) located on the operating floor of the Reactor Building. This 6-foot-high steel cylinder, used during normal refueling operations, was placed on top of the open vessel where the cylinder will remain throughout the entire defueling process. Once the IIF was attached, water was added to the Reactor Coolant System, filling the IIF to a depth of about 5 feet. This configuration provides shielding from radioactivity and will allow the plenum and fuel to be extracted through the IIF without flooding the refueling canal. Once the IIF was filled with water, workers installed a 1-3/4-inch-thick lead-lined steel work platform on top of the IIF, completing the head removal/IIF installation procedure. Figure 4 shows the IIF and platform in place on the reactor vessel.

During placement of the work platform, a minor malfunction of one of the switches on the polar crane caused it to stop when the work platform was within an inch of the IIF. Workers manually lowered the work platform the rest of the way by turning the turnbuckles on the crane's lift rigging.

Throughout the head removal process, the radiation levels were less than originally anticipated. Readings taken at the refueling canal were 3 R/hour, which was 10 to 15 times lower than projected. In the lead-curtain cubicle, workers experienced radiation levels of 30 mR/hour, lower than the 50 to 150 mR/hour anticipated. While removing their protective clothing, six workers experienced minor skin contamination, which was subsequently washed off with soap and water.

With the head lifted and the IIF in place, the first major phase toward successful cleanup has been accomplished. Currently, the schedule calls for initial plenum jacking in December 1984 and defueling to begin the following July.□

# Months of Preparation Lead to Safe Head Lift

The successful head lift in July 1984 climaxed months of preparatory work in and out of the TMI-2 Reactor Building. Safety played a key role throughout the operation, from underhead characterization to placement of the head on the storage stand.

One of the early objectives of the TI&EP's Reactor Evaluation Program was to determine the best approach to safely remove the reactor vessel head. The approach chosen was to remove the head dry, without flooding the refueling canal. This is essentially the same technique used in normal refueling operations and was considerably less time consuming than removing the head wet, which would have required subsequent decontamination of the refueling canal and processing of the canal water.

The Underhead Characterization Program confirmed the decision to remove the head dry. This program included the closed-circuit television examinations of surfaces under the head and on top of the plenum, radiation measurements inside the vessel, and analyses of debris samples from the plenum's upper surface.

While cameras saw much debris hanging from the underside of the plenum, its top surface—between the plenum and the head—showed no apparent damage or distortion and little debris. After obtaining gamma and beta radiation readings of this debris, technicians removed some samples which were tested for pyrophoric reaction. The test, conducted at Battelle Pacific Northwest Laboratory's TMI facility, demonstrated the debris posed no pyrophoric hazards.

The next major step in head removal preparations followed in February 1984, when the polar crane was successfully load tested and qualified to lift the reactor vessel head and service structure. The crane lifted and maneuvered a 214-ton load of missile shields, the lifting frame, and assorted rigging assemblies.

Major preparations were conducted in the five months preceding the actual lift. The 60 studs that fastened the head to the reactor vessel were partially detensioned to identify the studs that might have been stuck as a result of corrosion. Studs are detensioned by first stretching the studs and then loosening the nuts on them (see Figure 5). As expected, workers encountered some difficulty turning the stud nuts but succeeded using penetrating oil and a striking bar and hammer. Two of the studs were removed at that time, leaving holes in the head flange that later were lined up with the two guide pins on the storage stand on which the head was seated. In a later entry, the workers fully detensioned and removed the other 58 stud and nut assemblies, each weighing 670 lb, and placed them in storage racks. Finally, the stud holes were filled with a preservative and sealed, preventing them from corroding.

*Figure 5.* **This closeup shows some of the 60 studs that fastened the TMI-2 reactor head to the reactor vessel. The nut on the lower portion of each stud maintains tension on that stud.**

After the head studs were partially detensioned, the reactor vessel was refilled and pressurized. Processing of the Reactor Coolant System water could then resume. By sending the water through the Submerged Demineralizer System, its radioactivity was reduced. Also, the water's boron concentration was increased from 3700 to about 5000 ppm, thus increasing the safety margin for prevention of criticality (nuclear chain reaction) during later defueling operations. After the processing was complete, the reactor vessel was depressurized and water partially drained to below the reactor vessel flange before head lift.

Clearing a path for the head to be transported through the south end of the refueling canal, the auxiliary fuel handling bridge was dismantled and moved to the north end of the canal. The bridge is a crane that straddles and trolleys over the refueling canal.

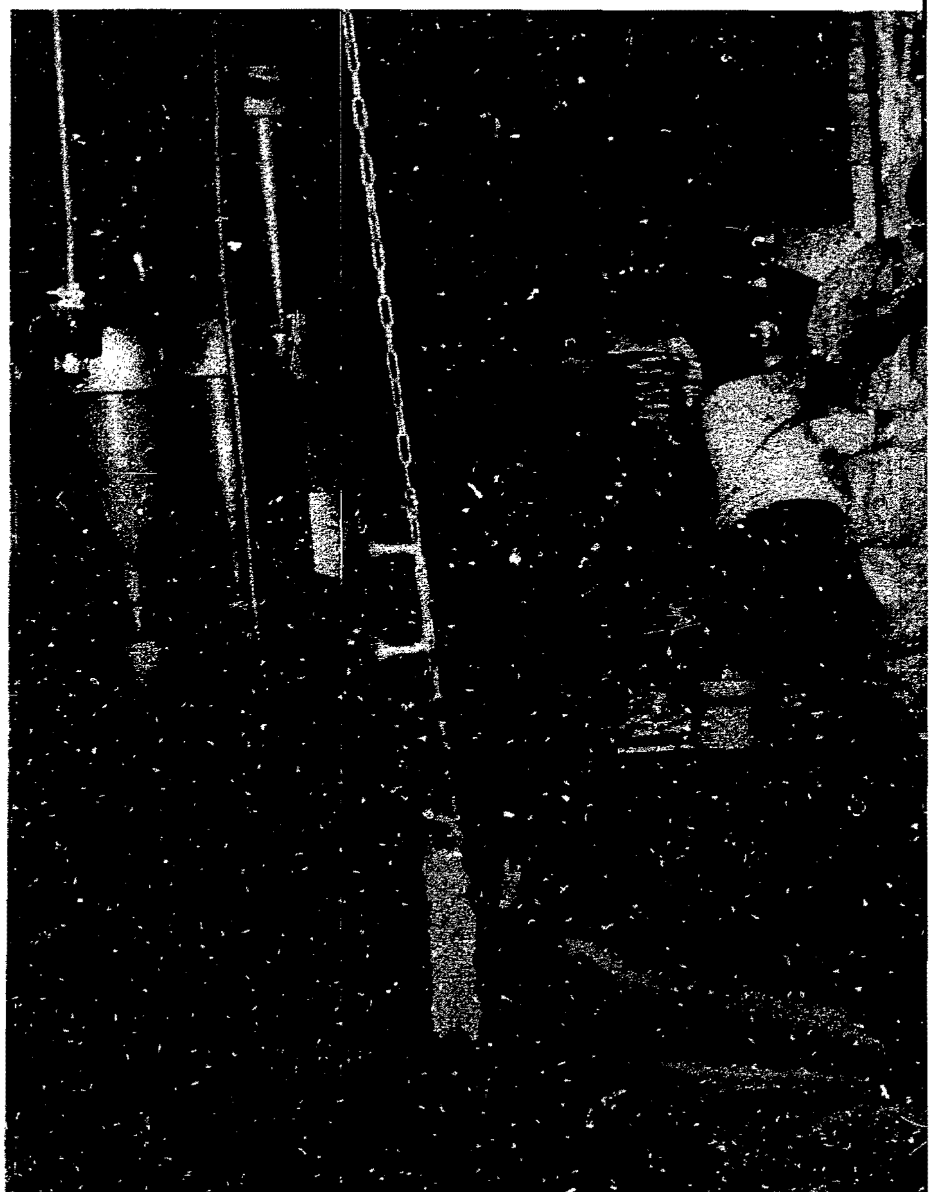


*Figure 6.* **A TMI-2 worker pours a sealant around the canal seal plate. The sealant and a metal seal plate were placed between the refueling canal and the reactor vessel so the canal could have been flooded, if necessary, for shielding.**

A few days before head lift, the remaining 66 lead screws were parked, or raised from inside the reactor vessel up into the reactor head service structure. Other important prelift jobs included installing cameras to monitor the head to maintain alignment as it was lifted; stripping the head of remaining insulation, wiring, piping, and equipment for adequate accessibility; preparing the IIF for placement on the reactor vessel after head removal; assembling in the Reactor Building the IIF work platform; and installing a system to process the Reactor Coolant System water within the reactor and IIF. The water is being pumped through this system to remove radioactivity from the reactor coolant system water, thereby keeping radiation levels low in work areas above the vessel.

Head lift planners were aware that head lift could have resulted in an air particulate radioactivity buildup or radiation intensity in the area around the top of the vessel, possibly requiring the refueling canal to be flooded. They therefore took precautions for such a contingency, fully inspecting the canal, sealing all penetrations in the canal walls and floors, and modifying the water systems so the canal could have been flooded with borated water—and subsequently drained.

A seal plate was installed, closing the gap between the reactor vessel and the refueling canal. On a partial mockup of the canal seal plate, workers practiced various techniques to apply the sealing compound that was to be used in the cavities and joints of the seal plate. Figure 6 shows a TMI-2 worker actually pouring the sealant around the reactor vessel.

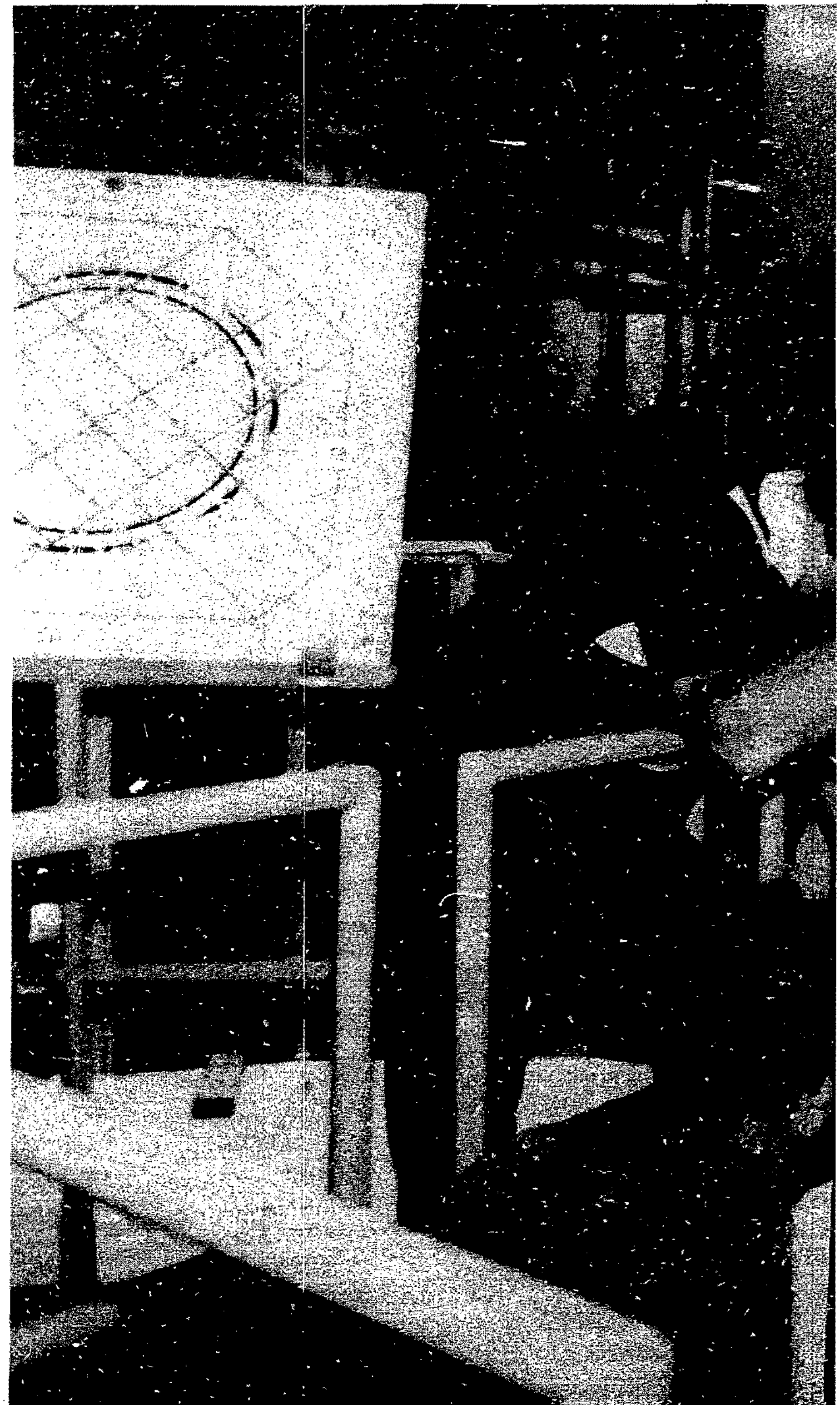
Training was, in fact, a critical part of the head removal effort. By rehearsing in the Unit 2 Turbine Building on mockups of the reactor head, IIF, IIF work platform, and other components and apparatus, workers were prepared to enter the Reactor Building and carry out their functions safely and efficiently. Consequently, they were able to reduce their time in the building and minimize their exposure.

Training was one of a number of items established to make head lift a safe activity. Some other controls included the use of shielding, protective clothing and respirators, personal dosimeters, radiation monitors, and television cameras, the combination of which were designed to keep radiation exposures to a minimum.

□

# Next Step:

# Plenum Jacking, Removal Planned



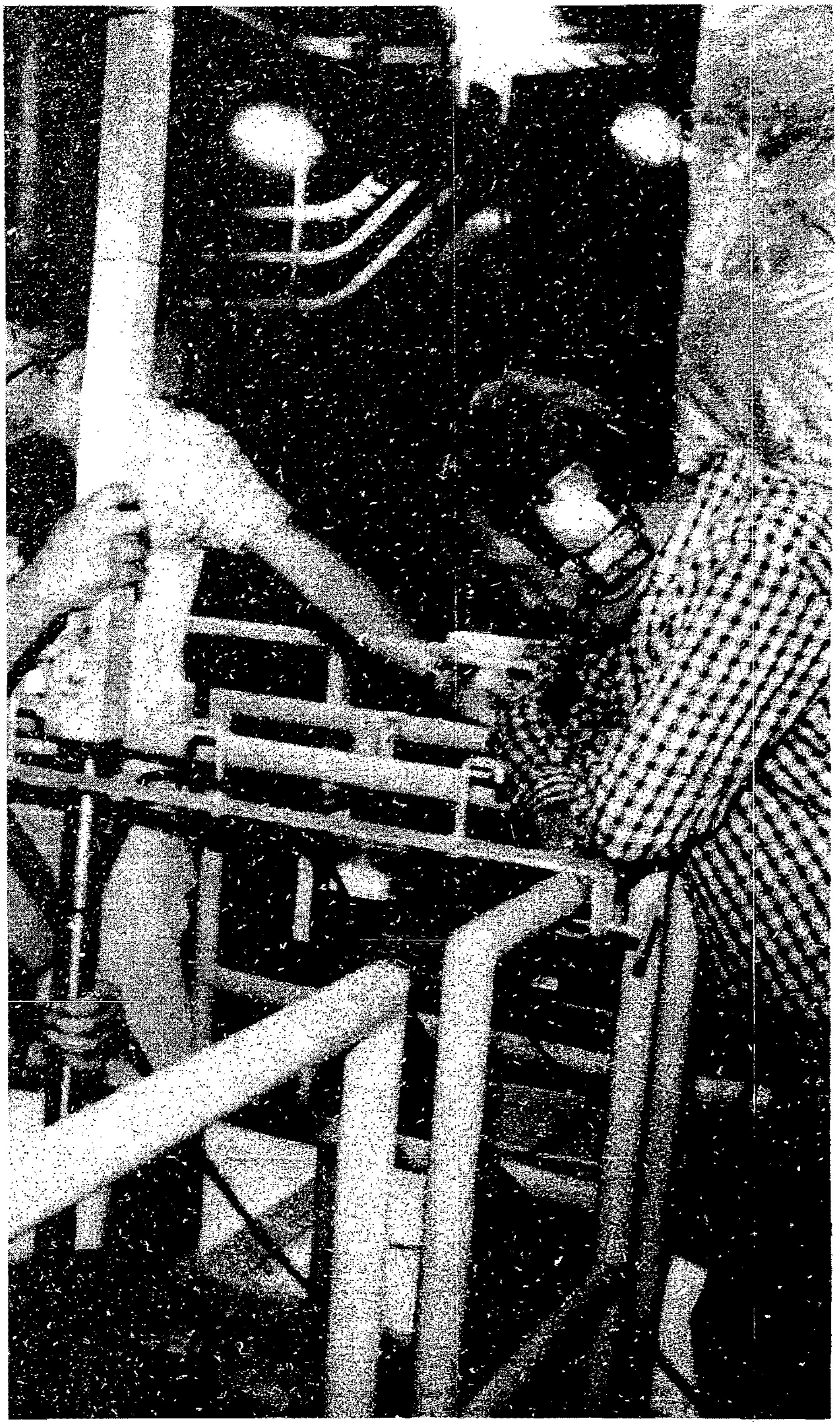
No sooner was the head removal project completed when the TMI-2 recovery program turned its primary focus to the next major stage in reactor disassembly: plenum removal.

The plenum assembly, a 55-ton cylindrical structure above the reactor core, houses the control rod guide tubes. It is scheduled for initial jacking in December and placement in the deep end of the refueling canal in May 1985. Over the past couple of months, the TI&EP and GPU Nuclear have been getting the plenum assembly ready for its initial jacking.

As a preparation, technicians are visually inspecting the plenum, using specially designed underwater cameras, recorders, lighting, and long-handled camera-positioning tools, to determine the amount of debris on the underside and peripheral surfaces of the plenum, as well as on top of the fuel assembly end fittings (see Figure 7). If a great amount of debris is found and considered to be a possible hindrance to the plenum lifting operation, the technicians may remove it by water lancing or vacuuming.

Also during the inspection, workers will attempt to separate unsupported end fittings using newly designed end fitting separation tools. If some end fittings remain attached, they may leave them since the plenum would still be able to sit evenly on a stand in the refueling canal.

End fitting separation is considered to be the first intentional movement of significant quantities of fuel in the damaged reactor core. This action can not cause



core criticality because the nearly 5000 ppm of boron in the Reactor Coolant System water in the vessel prevents criticality, regardless of fuel geometry.

The visual inspection of the plenum is not designed solely to check for debris and to test the knock-off tools, but also to see how much clearance remains in certain normally tight areas between the plenum and the core support shield that encircles the reactor vessel. Technicians want to establish whether the plenum has been damaged or distorted in these vital areas.

In December, workers operating four 60-ton hydraulic jacks will initially lift the plenum about 2-1/2 inches. The workers will then check for fuel separation, after which they will jack the plenum another 6-1/2 inches to be sure the plenum has a free path out of the reactor vessel.

The work will then be completed in early 1985, when a dam will be installed to hold water in the deep end of the refueling canal, a plenum storage stand will be put in place, the deep end will be flooded, and the plenum will be lifted, placed on its stand, and covered.

The outcome of this entire phase of the reactor disassembly project will be detailed in a future *Update* issue. □

*Figure 7.* **Workers lower new plenum inspection equipment into a large model of the TMI-2 reactor as they receive training in the plant's Turbine Building. The grid on the map of the plenum (left) provides guidance.**

# The TI&EP— What Has it Accomplished? What is in the Future?

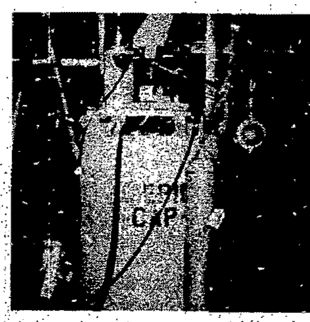
The safe removal of the TMI-2 reactor vessel head marked the successful completion of Phase 1 of the defueling sequence. Many TI&EP sponsored activities, along with intensive head lift preparations, contributed to the achievement of this major milestone. These activities began in 1980 when the DOE Technical Integration Office (TIO) was established.

The first major step toward defueling the damaged reactor occurred in July 1980 when the first manned entry into the Reactor Building occurred. To support this activity, the TI&EP established a Citizens' Radiation Monitoring Program, which proved to be one influential factor in alleviating the fears of local residents regarding adequacy of monitoring during

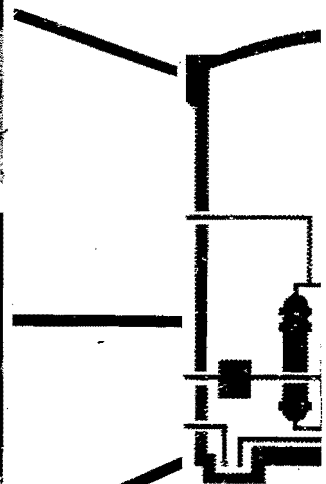
## Summa Cleanu

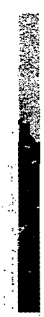
Polar Crane Inspection

Gross Decontamination



Basement Water Processing



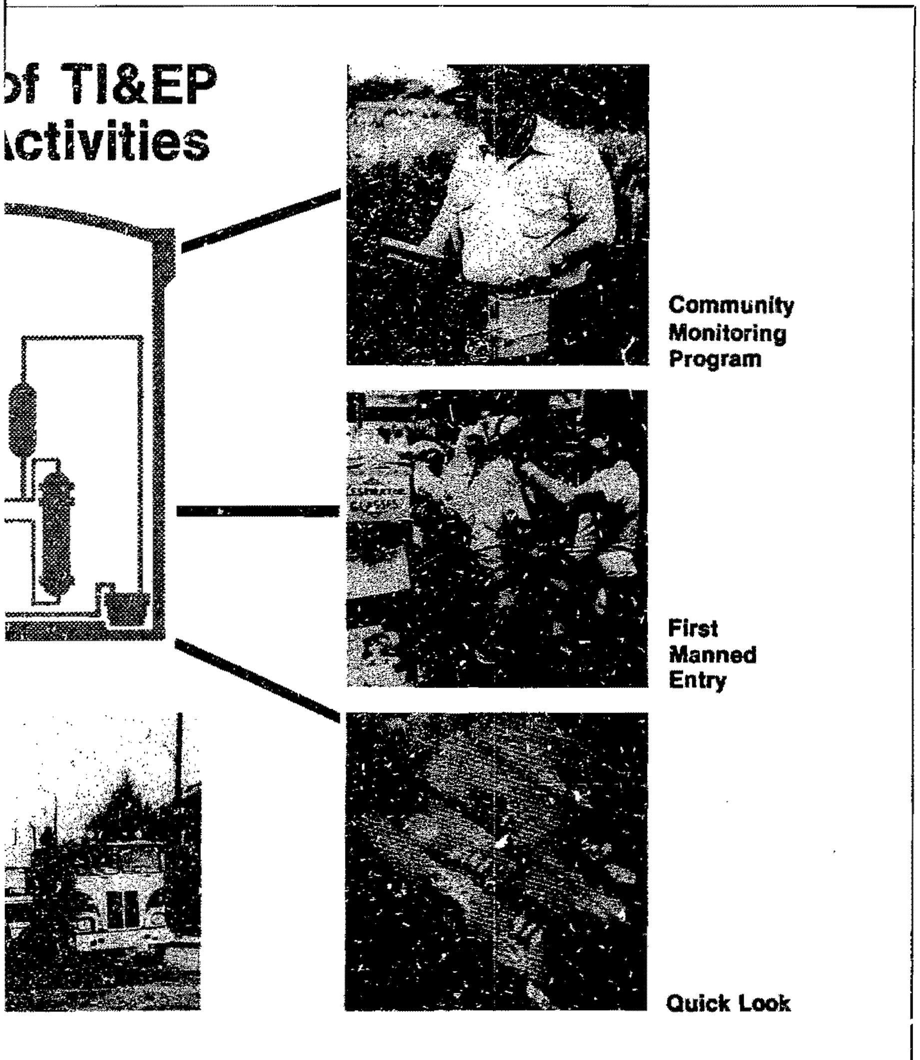


SDS & EPICOR Waste Shipments

the venting of $^{85}Kr$ from the Reactor Building—a prerequisite for manned entries. The program was designed to provide a credible source of information about radiation levels to the citizens in the communities adjacent to TMI during $^{85}Kr$ venting. The program represented a unique effort to build citizen confidence in public information and remains active in six communities today.

As manned entries into the Reactor Building increased, the TI&EP sponsored early inspections of the polar crane. These inspections provided recovery engineers with vital information on the extent of damage to the crane so that a safe, cost effective refurbishment of the necessary crane components could be conducted as expeditiously as possible. TI&EP engineers also provided technical electrical engineering evaluations to support the polar crane recovery—a critical path milestone for head removal that was completed in February 1984.

Probably the single TI&EP sponsored event that provided the greatest impact on the cleanup occurred in July and August of 1983 when the first inspections inside the reactor were conducted. Not only did this activity provide the first pictures of the actual conditions of the core, but it conclusively demonstrated that work in and around the reactor itself could be performed safely and efficiently. The activity, called "Quick Look," also proved that reactor internal components could be safely removed and handled and it paved the way for future underhead and in-vessel (core) characterization programs.




Other TI&EP activities also provided valuable contributions to the cleanup, but were not nearly as visible as Quick Look or head lift. Some of those activities included the gross decontamination experiment designed to determine the most effective means of reducing loose surface contamination, fission product deposition and mass balance, Reactor Building characterization, and shipping and disposal of accident generated wastes.

A major milestone in the Waste Immobilization Program was reached in the summer of 1983 when the last ion-exchange wastes used to decontaminate accident water were shipped from the Island for research and development projects and disposal. The two ion-exchange media systems, called EPICOR II and Submerged Demineralizer System (SDS), decontaminated more than a million gallons of accident generated water and captured approximately 95% of the radioactive elements released from the Reactor Coolant System as a result of the accident. (See articles published in previous editions of the *Update*.)

Another major cleanup milestone, elution of cesium from the plant's Makeup and Purification System demineralizer resin, is scheduled for completion in late 1984. Completion of this activity will essentially complete the Waste Immobilization Program's role in the TMI-2 cleanup.

Now that the head has been removed, the major thrust of the TI&EP is toward plenum removal. In addition, the defueling and core shipping phase is gaining momentum.

The plenum inspection equipment has already arrived on the Island, and training for the actual plenum inspections is well underway. The inspections, scheduled to begin in October, will be followed by removal of fuel rod stubs that are adhering to the plenum's underside. Once this step is complete, the plenum will be raised some 2-1/2 inches using hydraulic jacks to check for intact fuel assembly separation. This operation is currently scheduled to be completed by the end of 1984 and will be followed by transport of the plenum assembly to a storage stand located in the deep end of the refueling canal in the spring of 1985.

The defueling and core shipping activities have made significant progress. Westinghouse Electric Corporation, the defueling equipment contractor, has completed the preliminary design for the defueling tooling. The tooling final design and fabrication are expected to be completed before July 1985, when early defueling is currently scheduled to begin. Early defueling, which basically consists of a vacuuming technique, is projected to be completed by early fall of 1985 and will be followed by bulk defueling. Preliminary design of the fuel shipping/storage canisters is essentially complete. The first canisters are scheduled for delivery in early spring.

After completing many months of engineering evaluations and studies, TI&EP engineers selected the cask designed for rail shipping as the best method for transporting the TMI-2 core to the Idaho National Engineering Laboratory (INEL). Based on this concept, engineers have begun the preliminary cask design.

In addition to the plenum and core activities, the TI&EP is continuing to support the cleanup effort by analyzing samples of core materials and internal components. These efforts, as well as similar efforts in the past, will provide GPU Nuclear recovery engineers with the necessary data to formulate the best approach in solving complex recovery problems. □

# Videotapes Detail Head Removal Operations and Successful Waste Disposal System

The TI&EP recently completed two videotapes, now available for loan without charge. One of the programs, titled "TMI-2 Head Removal—One Step Closer to Recovery," details the head removal operation carried out July 24 through July 27, 1984, in Unit 2 at TMI. With actual footage from inside the Reactor Building, this videotape takes the viewer step-by-step through the lift, transport, and storage of the reactor vessel head. The program also discusses the followup work of shielding and covering the opened reactor vessel and some of the preparatory work done in the months previous to the major event.

"EPICOR II: The Evolution of a Successful Waste Disposal System," also recently released, examines how this demineralizer system processed contaminated water through three stages of organic and inorganic ion-exchange media. The videotape specifically discusses EPICOR II system processing of the water, development of a prototype gas sampler that sampled and purged the EPICOR II liners of radiolytic gas, shipments of the liners to the INEL for major research and development studies, and preparations for liner burial in high integrity containers. □

These videotapes may be obtained by contacting Kim Haddock, EG&G Idaho, Inc., TMI Site Office, P.O. Box 88, Middletown, PA 17057, telephone FTS 590-1019 or (717) 948-1019.

# TMI-2 TOPICS

## TWO DEBRIS CHARACTERIZATION TECHNIQUES FIELD-PROVEN

Engineers at TMI and the INEL have completed an extensive study of various nondestructive assay methods to locate and characterize debris distributed in the TMI-2 primary coolant and connecting piping systems. As a result of this work, they have found two techniques to be highly feasible.

The first technique, ultrasonic detection, uses ultrasound beamed through the pipe wall, then reflected back from the surface being examined. From the reflected ultrasound, or echo, a small computer constructs a contour map of the pipe's inner surface and the debris. Using this technique, engineers are capable of locating a full range of debris, including complete and fragmented fuel pellets, pieces of nonfuel material, and fine powder.

The second technique, passive gamma-ray detection, uses measurements of the gamma rays associated with the decay of certain fission products in fuel to detect and characterize fuel debris in the piping. A high-resolution gamma spectrometer was used in experiments to detect the fission product $^{144}Ce$, chosen for its chemical inertness, low volatility, long half-life, and associated high-energy gamma rays.

Each technique has its disadvantages, but both are field-proven, and test engineers believe the advantages far outweigh the disadvantages. Among the disadvantages, the ultrasonic method cannot distinguish between fuel and nonfuel debris, and the shell walls of piping insulation degrade acoustic signals, so the insulation must be removed for the ultrasonic technique to be effective. The passive gamma-ray technique cannot detect nonfuel debris.

However, the advantages are the gamma-ray technique is especially appropriate for assaying fuel debris in piping, whether or not the pipe is insulated. Also, the two techniques are complementary; used together, engineers can locate fuel and nonfuel debris, determine fuel and nonfuel fractions, and measure the amount, thickness, and physical distribution of all forms of debris in reactor plant piping systems. And both techniques use commercially available equipment.

## BIAS VOLTAGE MEASUREMENTS OF LPM CHARGE CONVERTERS MORE RELIABLE

In all pressurized water reactors licensed since 1978, the proper operation of the loose parts monitoring (LPM) system of the reactor vessel and related reactor coolant components must be demonstrated on a regular basis. In some reactors, the system's performance is a limiting condition for continued operation. But the normal routine surveillance procedures, which rely on audio output, will not detect when the system is degrading. A more reliable method of monitoring the state-of-health of an LPM system is by taking regular dc bias voltage measurements of the converters. This is the conclusion of the DOE Instrumentation and Electrical (I&E) Program, which has been researching selected instrumentation and electrical components used in TMI-2 and other nuclear power facilities.

After studying LPM system charge converters removed from the TMI-2 and Sequoyah-1 nuclear power stations, I&E engineers found that the converters, which use field effect transistors of metal oxide silicon, degraded as a function of accumulated radiation dose. These converters, however, were not designed to be radiation tolerant, nor does the manufacturer, Endevco, claim them to be. The TMI-2 instruments had been mounted in low radiation dose areas but failed after being exposed to unusually high radiation after the accident. The Sequoyah-1 charge converters had been mounted under the reactor vessel where they failed as a result of high accumulated radiation dose after 156 effective full-power days.

Plants that use charge converters that are not radiation qualified are recommended to take regular measurements of converter dc bias voltage, which will shift upwards as radiation dose is accumulated until the limit of the power supply rail voltage, normally 30 volts, is reached. By measuring the charge converter dc bias voltage and looking for a higher-than-normal level, plant operators can effectively monitor radiation degradation. The normal bias voltages for the TMI-2 and Sequoyah-1 charge converters were 13.5 and 18 volts, respectively.

In monitoring the converter's audio output, the only normal indication of degradation is a decrease in the usual background vibration levels; this output is not a constant that would indicate to personnel that the converter degraded since its last test. Consequently, a plant could be operating in violation of technical specifications and U.S. NRC Regulatory Guide 1.133 R1, with control room personnel unaware of the condition.

In response to its failed charge converters, Sequoyah-1 replaced its units with temperature and radiation hardened converters. All nuclear power plants are recommended to consider installing charge converters with temperature and radiation tolerant components able to withstand normal plant conditions. Strategic location and shielding of converters can also significantly reduce radiation damage, prolong the service life, and increase the reliability of radiation sensitive equipment installed in a reactor building.

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