As seen in the December 2009 issue of **Nuclear News**

The cleanup at Dounreay: Using a mixed bag of robotics and remote systems

BY DICK KOVAN

A wide range of innovative robotics and remote systems are being deployed at Dounreay, in Scotland, with the goal of decommissioning and closing the site by 2025.

THE DOUNREAY SITE, located on the windswept north coast of Scotland, is the United Kingdom's former center for fast reactor research and development. In the late 1990s, the U.K. government decided that Dounreay had served its purpose and should close. Since then, the site has been in the decommissioning and closure phase.

By the end of the 1990s, the United Kingdom Atomic Energy Authority (UKAEA), which then owned and operated Dounreay, had devised a plan to decommission and close the site by 2060. In 2007, however, the ownership of the site was taken over by the Nuclear Decommissioning Authority (NDA), which has since put forward much more ambitious plans for closing the site.

Under the NDA's closure program, all redundant facilities at the Dounreay site will have been cleaned out and demolished by 2025. Some packaged intermediate-level wastes consigned for disposal or long-term storage, however, will remain on site in secure, aboveground storage until the authorities in Scotland choose a final route for its disposal. Regarding any remaining contaminated ground, the intention is to allow it to decay *in situ*. This means that parts of the site will remain off limits to the public until about 2300, when the radioactive material will have decayed to background levels.

Another structure that will remain is the steel sphere that originally housed the site's first fast reactor. While a decision on its future has not yet been made, one option is to name the sphere a heritage site and leave it in place.

To achieve the 2025 target, a considerable investment is being made, including the development of a wide range of robotic and remote systems to assist with the inspection and cleanup of the various facilities at the site.

Site closure program

In 2008, the operation of the site was transferred to Dounreay Site Restoration Limited (DSRL), a wholly owned subsidiary of the UKAEA that operates under contract to the NDA. DSRL is now responsible for completing the site cleanup and closure program, which involves decommissioning many different plants, as well as dealing with a legacy of untreated radioactive waste and contamination.

The main facilities to be dismantled are the Dounreay Fast Reactor (DFR), a 60-MWt experimental fast breeder reactor that went critical in 1959 and was shut down in 1977, and the Prototype Fast Reactor, a 250-MWe fast breeder reactor that went critical in 1974 and was shut down in 1994. The liquid metals that were used to cool the reactors are considered to be the major hazards at Dounreay, requiring the development of a large range of remote systems to carry out the dismantling operations.

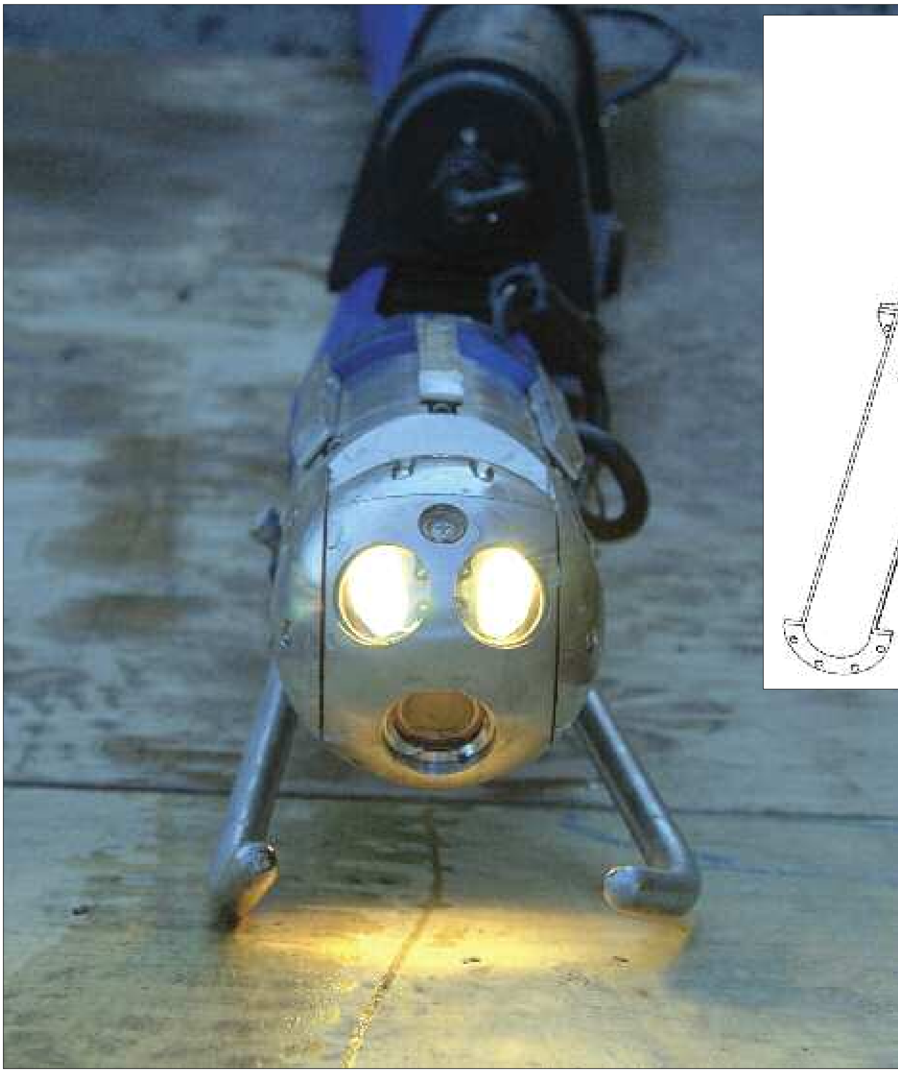
A particular problem at the DFR involves the breeder fuel elements that remain in the reactor. While the fueling machine had relatively little difficulty removing the reactor's active fuel elements, it was unable to cope with the 1000 or so breeder elements, many of which were damaged in attempts to remove them. A major project was launched to develop suitable tools to complete the defueling.

The manner in which waste and effluent were managed in the early days of operations at the site has left a difficult legacy that must now be dealt with. This includes problems such as the underground silo into which all kinds of radioactive waste was dumped in the 1960s and 1970s, and the dispersal of thousands of tiny radioactive particles into the sea, which eventually spread along the seabed and onto some beaches. Every summer, a remotely operated vehicle travels the seabed searching for and removing these particles.

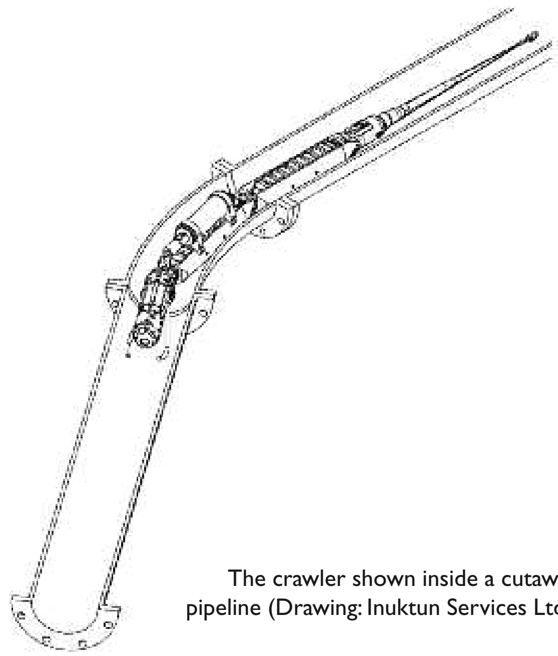
The following stories tell of some of the innovative uses of robotics and remote systems that are being developed and implemented at Dounreay for plant dismantlement, as well as for removing radioactive waste and contamination.

"Worm" probe crawls through subterranean discharge pipeline

Early this year, a high-tech "worm" probe was used to explore a subterranean pipeline that between 1957 and 1992 had discharged



A front view of the "worm" probe crawler (Photo: Martin Howse)



The crawler shown inside a cutaway pipeline (Drawing: Inuktun Services Ltd.)

radioactive effluent to the sea. The pipe crawler sent back video and radiation readings during its five-day journey some 45 meters underground. The data are being used by a project team that is investigating how to leave the disused system in a safe condition as part of the site's cleanup.

The mission of the remotely operated vehicle was to look for signs of structural degradation, trapped debris, and radioactive contamination, explained Martin Howse, project manager. He added that the findings would allow the team to decide on the best course of action, with the intention of making a proposal to the Scottish Environmental Protection Agency by the end of the year.

The pipeline consists of a bundle of four cast-iron pipes, each 23 cm in diameter, that was laid in the 1950s to discharge effluent from the fast reactor experiment. At one end it was connected to two tanks where effluent drained from the reactors, chemical plants, and waste facilities. The pipeline descended toward the sea along a sloping adit to a tunnel excavated 25 m beneath the seabed. At the end of the tunnel, some 600 m offshore, the pipeline terminated in a diffuser attached to vertical risers that exited on the seabed 20 m beneath the waves.

The pipes were encased in a thick concrete sleeve that runs along one side of the tunnel. When construction was completed in 1957, the tunnel was abandoned and allowed to flood. "The tunnel system has been flooded for more than half a century," Howse said, "so we don't know what condition the pipeline is in or if it is safe to leave in place."

The performance of the subsea discharge system started to deteriorate in the late 1970s, but it was not taken out of routine service until 1992, when a new plastic pipeline was installed in the tunnel and connected to a modern diffuser on the seabed.

The head of the pipe crawler is 2.5 m long and 15 cm in diameter, and its flexible, tracked chassis can turn through bends in the pipes. An umbilical "tail" allows the pipeline crawler to be controlled remotely from the surface, where the project team can view real-time video and radiation readings.

The two companies that carried out the survey, MSIS and Hydropulsion, developed expertise in remote inspections in oil and gas production operations in the North Sea.

Cameras to assess underground silo, waste

A decommissioning team has looked inside an underground silo where intermediate-level radioactive waste has lain submerged in water for as long as 40 years. To perform this task, two remotely operated cameras had to penetrate the 1.2-m-thick concrete roof. The two-week operation provided images of the internal condition of the silo, as well as the state of the waste that has been deposited there, in preparation for the start of work to clean it out.

The facility resembles a 9-m-deep swimming pool, lined on all sides with thick concrete and divided in the middle by a partition wall. Much of the 750 metric tons of waste inside the silo is metal and includes failed and redundant equipment, fuel element transport cans, and debris from fuel, such as cladding, end fittings, wrappers, and swarf. Other waste dumped into the silo includes plastic, glass, paper, and filters. The silo was filled with water to cool the waste and to shield operators from radiation.

The roof of the silo, which is at ground level, features four posting ports that starting in 1971 were used on more than 16 000 occasions to drop waste into the water-filled vaults below. The final consignment of waste was sent there in 1998, and it has remained undisturbed since then.

Two video cameras, together with lighting, were used, one to scan the condition of the structure and the other to view the condition of the waste. The drillholes that were created to allow the introduction of the cameras into the silo were plugged when the operation was completed, and controls were put in place to guard against contamination.

The analysis of the concrete cores resulting from the creation of the drillholes in the

Accumulated waste inside the silo in the 1980s (Photo: DSRL/NDA)

roof of the silo will provide information about the structural integrity of the roof. This will be helpful to the engineers who will design the equipment for the removal of the roof when the waste is ultimately retrieved from the silo.

The next task will be to design the facilities needed to retrieve the waste from the silo and the material in its predecessor depository, a nearby shaft. Detailed designs are expected to be ready by 2012, when construction companies will bid for the contract.

Offshore cleanup of spent fuel particles continues

More than a hundred radioactive "particles"—fragments of spent nuclear fuel—were removed from the seabed this past summer in the latest phase of work to clean up the marine environment around the Dounreay site. Of these, 29 were in the hazard category defined as a "significant" threat to health. The particles were detected and retrieved by a remotely operated vehicle (ROV) called TROL (Tracked Remote Offshore Logging), which systematically scanned some 75 000 m^2 of seabed and retrieved particles detected in the sediment. TROL is a tracked ROV unit developed by the locally based company Fathoms Limited. The ROV is a highly reliable and maneuverable vehicle that can operate to a depth of 100 m and is able to perform real-time gamma spectroscopy.

The work to address the legacy of radioactive particles began in August 2008 following extensive research and public consultation about the best practicable

The TROL being readied for deployment (above) and during a search-and-retrieve operation (left) (Photos: DSRL/NDA)

environmental option for dealing with the problem. During the initial demonstration phase in 2008, 55 particles were recovered.

The particles are fragments of irradiated fuel that have been discharged to the sea as a result of reprocessing operations at Dounreay during the 1960s and 1970s. Improvements in the processing of fuel and the release of waste since the 1970s have significantly reduced the discharges of such fragments.

The most hazardous fragments have been found near the old discharge point on the seabed and the foreshore at Dounreay, which has been closed to the public. The disintegration of these fragments is believed to be the source of smaller, less hazardous particles detected on local beaches. Independent experts have assessed the risk to beachgoers and found it to be low, and so the beaches remain open to the public. Fishing is banned in the area near Dounreay where the most hazardous particles have been found.

The work was carried out in water up to 30 m deep and resulted in the recovery of 115 particles during the two-month operation this summer. Besides the 29 fragments in the higher hazard category that were recovered, another 16 suspected fragments detected by the TROL also gave readings in this category but were not retrieved. Six of these could not be targeted accurately for retrieval, and 10 were buried in the sediment deeper than the 4-cm reach of the ROV retrieval system. These operations will continue over several summers to remove the most active particles.

Before the retrieval operations started, parts of the seabed were monitored to provide baseline information that will allow the effect of the seabed recovery to be monitored. This included an area on the edge of the fishing exclusion zone and another area between the old diffuser and Sandside Bay, where a number of particles have been found. This will assist in understanding the movement of particles over the next few years.

Phil Cartwright, the DSRL project manager responsible for the work, said, "Our objective is to reduce the number of particles on the seabed and provide information that will assist planning of work in future years." He added, "The retrieval of 115 particles, with total radioactivity of 500 million becquerels is a positive start to the seabed cleanup."

DSRL provides a list on its Web site of all particles detected around the site.

"Our objective is to reduce the number of particles on the seabed and provide information that will assist planning of work in future years."

Drilling camera photographs core sodium residue

While the 1500 metric tons of bulk sodium coolant used to cool Dounreay's Prototype Fast Reactor has been drained and disposed of, a considerable amount of sodium residue remains attached to surfaces and deposited in cracks in the reactor and its internals. This residue—which would ignite if it were to come into contact with air—must be removed before the reactor can finally be cut up and dismantled. To maneuver a camera safely into the highly radioactive core took some ingenuity on the part of the designers.

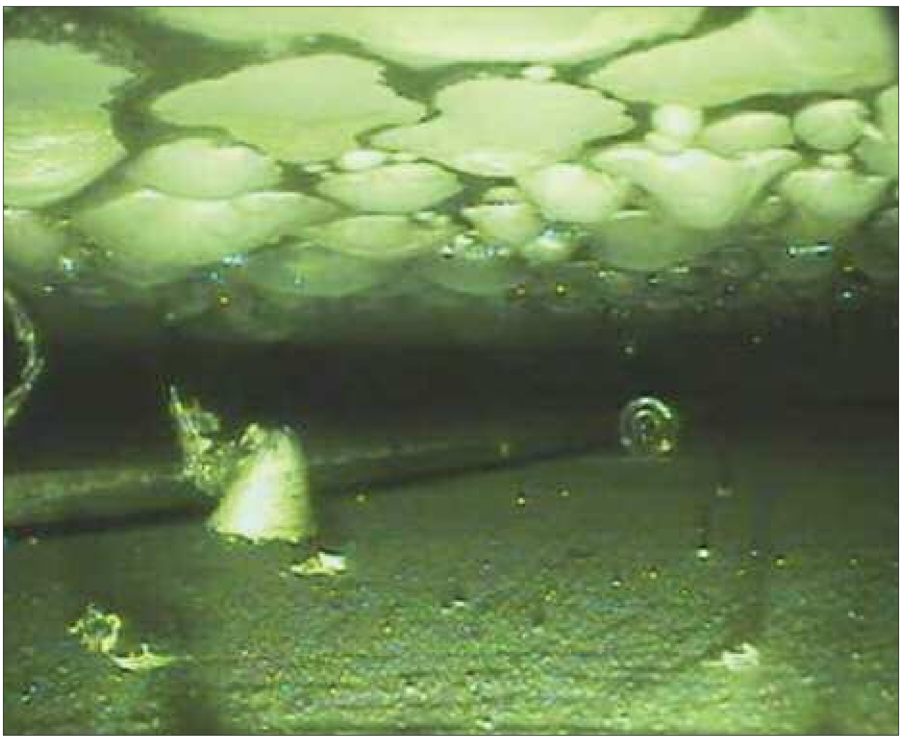
To achieve entry, DSRL's specialized design team designed and tested an innovative purpose-built drilling probe. The device has the ability to drill through the reactor roof and then capture photographic footage of the sodium deposits in an extreme environment of high radiation levels.

Once the drilling was completed, a 6-mm-diameter camera encased in a stainless steel tube was inserted more than 2 m down into the reactor. Using this camera, the project team members were able to obtain clear images of the upper regions of the reactor where 31 stainless steel insulation plates are located and to survey the sodium residue that had built up on the plates over time. The metal plates were a crucial part of the system that cooled the reactor roof. The sodium looks like volcanic lava encrusting the surfaces of the metal. The images and radiation-level readings have provided the decommissioning team with valuable information that will be used for planning the dismantlement of the plant.

"The drilling of the thin plates presented a unique challenge, as they are not well supported," explained Calder Bain, who was responsible for the design of the equipment. "Their flexible and flimsy construction meant taking extra care to prevent the drill breaking and being unrecoverable," he added. "The design was kept as simple as possible after trials on a test section revealed the intricate nature of the process."

The contractors that carried out the work were JGC Engineering & Technical Services and Nuvia Limited.

A 3-D computer rendering of the remote orbital welding station (Graphic: DSRL/NDA)



A view from the PFR drilling camera shows lava-like sodium residue. (Photo: DSRL/NDA)

Remote orbital welding station to seal fuel containers

The spent fuel from Dounreay's Prototype Fast Reactor (PFR) will be stored in specially designed stainless steel containers. One of the robotic systems developed for handling the spent fuel is a unique orbital welding system that will remotely seal the container lids from within the PFR's irradiated fuel cave. The system will also leak test the weld to ensure that the container is fully sealed.

When built, the equipment will first be mounted in the reactor hall cave mock-up. Remote assembly trials will be carried out on the welding station to ensure that it can be assembled within the confined cave environment and to provide operator training on the use of the equipment in safe and clean surroundings.

The accompanying computer-generated diagram shows a 3-D image of the remote orbital welding system as it will appear in the irradiated fuel cave. In the diagram, an irradiated fuel container is shown in place, ready for the welding of its lid.

Irradiated fuel from the PFR will be packaged into the new containers for long-term storage and will be held in an on-site facility pending a decision regarding its reuse or management elsewhere. Dounreay will require as many as 1000 of the fuel storage containers during the decommissioning of the site.

The contract to provide the containers was awarded to Nuvia. The manufacture and testing of the containers was subcontracted to local firm NES Engineering Ltd., which is also manufacturing the orbital welding equipment.

Continued

Breeder element removal tool installed in fast reactor

Previous difficulties in removing the nearly 1000 breeder fuel elements from the Dounreay Fast Reactor (DFR) prompted the development of a new system to dislodge and remove these elements. A versatile, remotely operated machine referred to as a retrieval cell has been built and installed within the steel containment sphere that houses the reactor. The retrieval cell contains a series of highly engineered, purpose-built tools, including cutting/grinding/pulling tools, designed to reach down inside the reactor vessel and take out the elements. As shown in the accompanying photograph, a mast towering 27 ft above the floor of the sphere is bolted onto the top of the retrieval cell, which in turn is bolted onto the rotating shields, allowing access to the inside of the reactor.

The breeder element removal tool, installed in the DFR's containment sphere. (Photo: DSRL/NDA)

The DFR's vented, high-enriched uranium metal fuel was cooled by NaK, a liquid alloy of sodium and potassium. While the HEU fuel has been removed from the core, remaining inside are 977 breeder elements, along with the primary NaK, which has high levels of radioactive contamination.

Some of the 8-ft-long breeder elements are now jammed or heavily damaged as a result of earlier defueling attempts, and it is anticipated that many others are warped and distorted or swollen. These will all have to be cut out of the reactor core before they can be removed. All of the operations will be conducted under a nitrogen environment to prevent the NaK coolant from igniting.

Once removed, the elements will be lifted into a cask and transported via a transfer tube to a process cell in the adjoining building. There they will be dismantled, washed, and packaged into 500-liter drums for on-site storage as intermediate-level waste prior to immobilization and long-term storage.

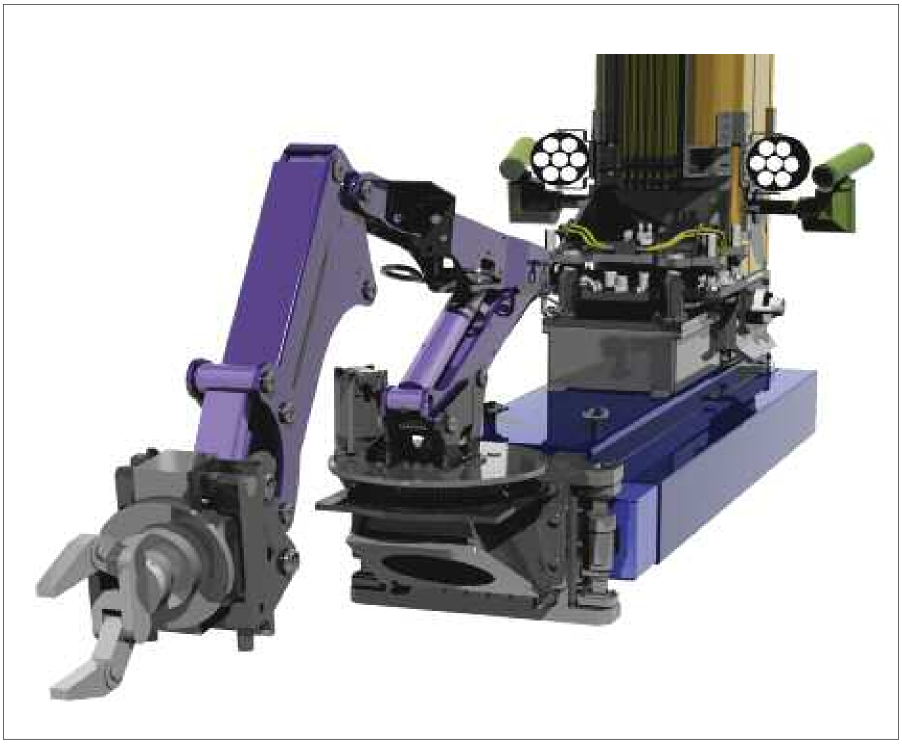
This unique machine, explained project manager Peter Poulton, is completely custom-made and is versatile enough to cut away every stuck element and remove it from the reactor. The retrieval cell and mast were built in Toulon, France, by Areva. DSRL engineers were in attendance during the testing of the equipment before it was shipped to Dounreay and installed in the sphere.

The operation to remove the breeder fuel is not expected to begin until 2012, once the bulk liquid-metal coolant has been drained and destroyed, and will take an estimated two to three years to complete.

Reactorsaurus: Pulling apart the PFR internals

In order to dismantle the large 250-MWe Prototype Fast Reactor (PFR), DSRL's design team has developed a versatile device called the reactor dismantling manipulator (RDM). A look at the accompanying computer image of the design shows why the giant 75-metric-ton device, which can deploy two large pincer arms and has roving photographic eyes, has been nicknamed "Reactorsaurus" by the project team.

The RDM is a large traversing carriage that incorporates a set of two 12-m masts, each with an extendable boom to which is attached a robotic arm that can reach 16 m down into the reactor vessel. Activated from a central control room, these arms are able to operate an array of size-reduction and handling tools, such as diamond wire and disks, hydraulic shears, oxy/propane and plasma cutting tools. When undertaking a typical cutting operation, one arm grasps the piece while the other does the cutting. Built into the device are six radiation-toler-



Computer image of the reactor dismantling manipulator, also known as “Reactorsaurus” (Graphic: DSRL/NDA)

ant cameras with audio capability that will relay images and sound back to the control room. Two cameras are mounted on the underside of the carriage, and another two at the bottom of each mast.

To ensure that the RDM will be able to deploy the tools to complete its tasks, a life-size model will be tested in an off-site purpose-built mock-up test facility replicating the circular reactor roof and three sectors of the reactor core covering 108 degrees of the total. This will also allow for the development of techniques and processes for the size-reduction and removal of the reactor components, simulating the challenges that will be encountered when the actual work starts. The mock-up will also be used to determine the most appropriate sequence for dismantling the reactor.

Before the RDM can begin the real work, a dismantling facility will be built around the reactor, providing a containment area for its safe dismantlement. The dismantling facility will have low- and intermediate-level waste processing routes for dealing with the contaminated parts, including steam-cleaning booths and a handling cell complete with an assay station that will allow for determining whether the part takes the low- or intermediate-level waste route.

The first part of the dismantling operation will be the removal of the 250-metric-ton rotating shield at the top of the reactor. Once this is done, the RDM will have access to the reactor and will be able to reach in to cut out and remove all the internals.

The dismantling team hopes that the contracts for the reactor mock-up can be put out to bid in the near future, followed by the RDM contract. The goal is to start commissioning the RDM in 2013.