

Mechanical Cutting of Irradiated Reactor Internal Components

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ABSTRACT

This paper discusses the use of mechanical cutting methods to volume reduce and package irradiated reactor internal components. The recent completion of the removal of the Reactor Vessel Internals (RVI) from within the Sacramento Municipal Utility District's (SMUD) Rancho Seco Nuclear Power Plant demonstrates that unlike previous methods used for similar projects, mechanical cutting minimizes exposure to workers, costly water cleanup, and excessive secondary waste generation.

INTRODUCTION

Decommissioning nuclear reactors often requires segmentation of large components to accommodate cask storage and/or shipments. Irradiated components such as reactor internals usually must be segmented underwater to shield the workers from excessive radiological exposure. At SMUD, mechanical cutting methods, such as sawing, machining, milling, and shearing, were primarily used underwater to segment 343,000 pounds of stainless steel reactor internal components, resulting in low radiological exposure, no additional water cleanup costs, and no secondary waste.

This achievement is a result of extensive preliminary planning, testing, committed project personnel and a overall corporate philosophy dedicated to providing the necessary resources to safely complete the SMUD internals segmentation project.

WORK DESCRIPTION

The SMUD reactor internal components consisted of the plenum assembly and the core support assembly. Approximately 48% of the material was segmented for boxes and shipped to a disposal site as Class A waste. Approximately 42% was segmented and placed into CNS 8-120 hardware liners for long-term storage or cask shipments to a disposal site as Class A, B, or C waste. The remaining 10% was Greater Than Class C (GTCC) waste and was segmented and placed into a spent fuel-type container for long-term storage on-site with the spent nuclear fuel.

Planning

Beginning in August 2003, the project planning began with the posting of the Request for Proposal (RFP). Proposal planning began with an extensive review of the RFP documents including the drawings, photographs, reports, system manuals, survey data and other documentation provided on the 2,772 MWt Babcock and Wilcox designed Pressurized Water Reactor (PWR) which ceased operation in June of 1989.

A full scale computer model of the Reactor Vessel Internals (RVI) was generated while lessons learned from the industry's previous commercial RVI projects were studied. This study included discussion of the available segmentation methods and graded each method with regard to the cutting ability, secondary waste generation, remote handling, ALARA, and practicality. Using this study, the RVI were broken down into individual components and the most appropriate segmentation method was chosen.

One of the first fundamental decisions made was the selection of mechanical segmentation processes as the primary method for segmentation and removal of all RVI components. While both plasma arc and abrasive water jet segmentation processes may have advantages in terms of production rates and delivery, the secondary wastes generated by these processes are not consistent with the objectives of minimizing worker exposure and secondary waste generation. In contrast, the only wastes produced by the mechanical segmentation methods are limited to metal chips and shavings that can be easily collected near the cut zone or after completion using simple and proven commercial vacuum devices. These materials can then be remotely transferred directly to the waste container.

Next, the appropriate physical locations were identified to perform segmentation of the individual RVI components. The refueling cavity at SMUD was large and provided sufficient space to dismantle, volume reduce and package while the RVI components remained shielded below the water surface of the cavity.

The available characterization data was analyzed along with the conceptual tool designs to determine the most efficient plan to segment the RVI while maximizing the volume of Class A waste that could ship for immediate disposal and the weight based package efficiency for all Class B and C waste destined for long term storage at the interim onsite storage facility.

After six issued addendums to the RFP, a thorough reply was issued in January 2004. This RFP included participation from other team members that provided Project Management, waste packaging and cavity water treatment. By February 2004, SMUD had selected this team.

Preliminary planning proceeded in the following months while appropriate licenses were obtained by all team members. This period allowed for contract negotiations with all team members and the refinement of the tooling conceptual designs and segmentation plan. This refinement resulted in the specification of the major segmentation tools, waste packages including boxes for low activity components, liners for high activity A, B, and C waste and a canister for the GTCC components designed in accordance with the existing independent spent fuel storage installation (ISFSI).

The refinement of the tooling concepts resulted in five mechanical cutting tools. These tools eventually performed 95% of the cutting required to complete packaging of the SMUD RVI. These tools included:

The Reciprocating Machine Tool (RMT) concept included a reciprocating 14-foot long bar containing ten cutter segments each 15 inches long. The cutting bar was to be mounted on two 30-foot towers to allow the tool to cut linearly in the horizontal direction. The bar would travel

vertically downward as the cutting progressed. The RMT was to be capable of cutting through components as wide as 13 feet and as tall as 10 feet.

The RMT was to be powered by a 60 hp hydraulic power and control unit. The motion mechanics of the blade were to be controlled using programmable logic controls that commanded the two tower mounted servomotors. Sensors and encoders were to be used to provide the controllers constant feedback relative to the blades position and direction of travel.

The final segmentation plan prescribed use of the RMT on the plenum assembly, plenum cover, upper grid and the lower internals of the SMUD RVI. Initially this included 18 individual cuts of up to ten feet deep and thirteen feet in width.

The Bolt Milling Tool (BMT) was to consist of a positioning frame and a three axis milling carriage that would ride on the frame. The tool was to be indexed from the core support grid and used to mill away the bolt heads attaching the core baffle plates to the baffle former plates. The baffle plates were then to be transferred to the GTCC canister for long-term storage.

This concept required the removal of exactly one thousand bolts that mounted the baffle plates to the former plates and each other. The core support structure will have been removed from the reactor vessel and staged in the refueling canal resulting in tool depth of over thirty five feet. The BMT will use integrally mounted cameras to target each of the bolts remotely. The removal of the bolts would also have to be removed in a specific pattern to assure that the assembly remains rigid until the last bolt is removed. This orchestrated sequence would require 52 moves and 5 tool reconfigurations.

Additionally, since the reactor baffle plates were classified as GTCC waste, any debris resulting from the milling of these bolts had to be captured, collected and loaded to the GTCC canister

The Bolt Shearing Tool (BeaST) concept consisted of a frame with multiple hydraulic cylinders to pull the baffle former plates from the core barrel by brute force, causing the former plate bolts to fail in tension. These former plates would also be transferred to the GTCC canister.

This concept took advantage of the available geometry of the former plates. These plate were fastened to the inside diameter of the core barrel and supported the baffle plates. Each former plate had flow holes to allow for the passage of reactor coolant between the annular space created by the core barrel and baffle plates. These holes were used to secure the BeaST while the large diameter cylinders would push into the core barrel with upwards of 750,000-pounds of force until each of the bolts failed in tension.

Reactor geometry would require two tools each of different shape. During the removal of the 64 plates, each tool will require reconfiguration three times.

Like the baffle plates, the former plates were also classified as GTCC waste. Since the bolts were to fail in tension, no additional cutting debris would be created and required no collection.

The Circumferential-Hydraulically Operated Rotating Cutting Equipment (C-HORCE) concept consisted of a clamping frame and a rotating table. Once the frame is clamped into position, the table would follow a radial rail driven by low speed hydraulic motors around a continuous gear.

A cutting blade holding replaceable carbide cutters is used to segment the 2-inch thick core barrel and thermal shield cylinder sections.

The C-HORCE will remain clamped to the remaining cylinder below the cut. Therefore, the dead load of the removed cylinder will be lifted prior to completion of the cut. Reactor geometry will require innovative rigging methods to remove the concentric cylinders after completion of the first cuts.

The final segmentation plan required seven cuts. Each of these cuts was to be made through 2-inch nominally thick cylinders with outside diameters of 145 and 148 inches.

The 38-inch diameter linearly traveling saw (38i) concept consisted of a 38-inch diameter carbide tipped circular saw blade mounted on one of the vertical tower provided with the RMT. The blade was to travel vertically allowing it to cut material as thick as 13 inches. A rotating table was to be used to position and secure the segments in place. Using hydraulic cylinders, the table could be rotated about its axis and allowed indexing of the work piece forward and aft of the blade.

The final segmentation plan prescribed use of the 38i to volume reduce for packaging the core support shield, core barrel and thermal shield

Design

Formal design and engineering commenced immediately upon receipt of the notice to proceed in June 2004. Design of the five segmentation tools began simultaneously. The design sequence for each tool began by expanding the conceptual design to a final design state. All project stakeholders were then invited to participate in a formal design review meeting. This meeting provided a forum to review the computer model of the tool and its application with the computer model of the internals. Comments were collected from all participants and incorporated into the final design. After design reviews, formal fabrication drawings were prepared and catalog items procured.

Testing

Prior to shipment of the segmentation tools to the project, each tool was subjected to a full scale mock-up as shown in Figure 1. The goal of this testing was to ensure that the design parameters specified for each tool are met on components of similar geometry and materials anticipated to be encountered during deployment.



Fig. 1. RMT mock-up testing.

Due to the scale of the actual RVI package within the SMUD reactor, the design of the test piece could not practically present all shapes to be encountered. The test piece design included a full scale section of the core barrel. This section would allow testing each of the tools at what was believed to be the most challenging for the project.

Tool assembly and testing began in November 2004. Testing revealed the following for each of the assembled tools.

RMT Testing: The cutter design proved to be the largest issue relative to the successful testing of the RMT. During testing, adjustments were made relative to the cutter hardness as well as geometry. Since the cutters are custom built, additional duration was required to order the revised design. Testing also revealed that specific cuts prescribed by the final segmentation plan could not be performed. This required significant revisions to the segmentation plan.

BMT Testing: Testing of the BMT was very successful. Continued testing was required to optimize cutter selection.

BeaST Testing: Initial testing of the BeaST revealed minor geometric changes to the body of each tool. These modifications were added and each configuration tested without incident.

C-HORCE Testing: The final design concept of the C-HORCE was to have two cutters in operation 180 degrees apart. Testing revealed that, without significant changes to the hydraulic control unit, operation of both cutting heads would not be possible. It was agreed to set the tool up with one cutting blade. Other changes included the addition of a gearbox on the rotational axis such that the forward motion could be controlled at low speeds. As with the BMT, continued testing was required to optimize cutter selection.

38i Testing: The 38i testing was very successful. The most significant challenge to the operation of the 38i was the ability to hold the component during cutting.

Mock-up testing was completed and tools shipped to the project in early March 2005.

Facility Overview

Segmentation of all RVI components were performed within the filled Refueling Cavity and Refueling Canal. The overall refueling cavity dimensions are approximately 51.5 feet (ft) long by 24.0 ft wide by 24 ft deep. The refueling canal is located immediately adjacent to the West side of the refueling cavity. The refueling canal dimensions are approximately 19.2 ft long by 24.0 ft wide by 37 ft deep.

The use of existing plant equipment during segmentation operations included use of the polar crane. In addition to the polar crane, two work platforms were designed to provide access to both ends of the refuel cavity. Each of these work platforms were fitted with rated lift trolleys for handling of segmented components as well as the tools. The work platforms occupied the same rails formally occupied by the reactors refueling fixture and were equipped with an electric trolley system to enable movement of the bridges along the rails.

Work Area Set-up

Segmentation of the reactor internals began with preparation of the refueling cavity for the pending segmentation activities as well as inspection of existing and available equipment for the general handling of the upper and lower internals. Prior to mobilization, review of relevant reference data was performed, including necessary nondestructive testing on equipment for certification prior to use.

The configuration of the refuel cavity was as follows: the reactor vessel head was removed from the containment building, the plenum assembly was removed and located in the "B" D-ring, there were no fuel assemblies in the core, and all control rod assemblies have been completely removed and processed, the reactor vessel contained five containers of sectioned incore detector tips, the fuel transfer canals were sealed and appropriately reinforced.

The RMT and associated work platform (see Figure 2) was installed in the area immediately adjacent to the east side of the reactor. The design of the work platform was to facilitate the deployment of the RMT. The platform was equipped with fixtures capable of supporting segmented pieces as they were cut.



Fig. 2. RMT and associated work platform prior to cavity flood up.

The internals support stand was positioned in the deep side of the cavity prior to flooding it with demineralized water. Segmentation activities performed in this area will utilize the BMT, BeaST and C-HORCE and include removal of the baffle plates and baffle former plates, separation of the core support shield, as well as partial segmentation of the thermal shield and core barrel.

Other activities to be completed prior to flooding the cavity with demineralized water included removal of the caged ladder on east wall of the cavity, removal of fixtures mounted to the southwest corner of the shallow portion of the cavity, and the removal of the lift fixture alignment cylinder.

The refuel cavity was filled in April 2005 to the normal refueling water elevation of 35'-0" for ALARA considerations.

Upon removal of the core support assembly from the reactor vessel, a cover structure was placed over the RV opening providing additional staging space for liners while protecting the seal ring and preventing migration of cutting debris into the reactor vessel.

Plenum Assembly

The plenum assembly or upper internals was completely independent from the core support structure. The assembly was comprised of four major components including the upper grid assembly, the control rod guide tubes, the plenum cylinder and the plenum cover. Total mass of the assembly was approximately 96,700 pounds containing a total activity of 177 Ci. Prior to

flooding the cavity, the assembly was removed and staged within one of the D-rings which formally housed the steam generators and/or pressurizers.

After the cavity was flooded and the core support structure was removed from the reactor vessel, the plenum assembly was located back to the cavity and placed on a fixture atop the RMT work station. Segmentation of the plenum assembly was performed while other items were removed from the core support assembly at the opposite end of the cavity.

The 38i was used to perform vertical cuts along the plenum cylinder. Once these cuts were completed the assembly was removed back to the D-Ring where other methods including hands on mechanical cutting, diamond wire saw and plasma arc cutting were used to reduce the assembly to sizes suitable for disposal in custom made type 7A boxes. The upper grid sections of the plenum assembly were returned to the RMT for volume reduction to sections suitable for disposal using four 8-120 style liners as Class B/C material.

As a result of this effort over 86% of the plenum assembly (by weight) was available for disposal as Class A waste.

Core Support Assembly

The core support assembly accounts for the balance of the RVI and included the baffle assembly, the core barrel, the thermal shield and the lower internals. Total mass of the assembly was approximately 246,300 pounds containing a total activity of 99,223 Ci. This massive stainless steel component stood over 30 feet tall and 12 feet in diameter.

Baffle Assembly

Inside the core barrel were a series of horizontal former plates and a series of vertical baffle plates. The horizontal former plates were bolted to the core barrel and the vertical baffle plates were bolted to the inner surface of the horizontal plates that formed an inner wall that aligned the fuel assemblies. All components of this assembly were classified as GTCC material and contained nearly 80% of the total activity contained within the core support assembly.

Baffle Plates

The BMT was used to remove the 1000 bolts to free the plates from the former plates. To remove the baffle plates, the tool required 52 separate applications. The maximum number of cycles per application was 33 bolts. Initially, as little as 5 bolts per cutter were removed and required many more cutters than planned. However, as the operators gained experience as many as 24 bolts were removed with a single cutter. This production per cutter was sufficient for 41 of the 52 applications.

Since this material had been classified as GTCC material, it was imperative to collect all cutting debris. A specifically designed machine chip collection system was used to provide point source capture of this cutting debris. As cutting progressed, long stringy chips produced large bundles of cutting debris. These large bundles were allowed to descend to the lower grid. At completion of the baffle plate removal, these bundles were easily collected and loaded to the GTCC basket for disposal.

Only one basket was fabricated to dispose of the 33,300 pounds of classified GTCC material. A very specific loading plan was used to ensure sufficient space was available.

Baffle Former Plates

The BeaST was used to remove the 64 baffle former plates. To enhance the visibility and deployment of the BeaST, select components were painted with bright colors such that the operators could confirm proper alignment prior to engaging the large cylinders.

The only technical problem encountered during deployment occurred at the middle elevation of former plates. At this elevation, the flow holes were reduced from 1.25-inches to 1-inch. The pins engaged through these holes failed during the first application at this elevation. After inspection by the project engineers, it was determined that the machining of the part was in error. The tapped hole in the end of the pin was too deep and intersected the shear region removing critical shear stress area. After replacement of the pins, no other failures were encountered.

After removal, each former plate was loaded to the GTCC canister in accordance with the prescribed loading plan.

Core Support Shield

The core support shield was a flanged cylinder that mated with the reactor vessel opening. The plenum assembly nested within the core support shield. Total mass of this component was approximately 65,400 pounds containing a total activity of 6.15 Ci. The core support shield stood nearly 10 feet tall, was over 12 feet in diameter and over 12 inches thick at its widest cross section as shown in Figure 3.



Fig. 3. Core support shield segment.

The C-HORCE was used to cut the core barrel just below the bolted connection with the core support shield. Aside from less than expected cutter life, the C-HORCE performed this cut without incident. A remote grapple was used to remotely change the blade without removing the tool from the core barrel. This enabled multiple retooling without abandoning the current kerf. To complete the 145 inch diameter cut thru the 2 inch thick body used 8 blades.

The core support shield was cut into eight 45 degree segments. Due to its low activity, two sections were loaded to a custom built type 7A box and made available for immediate disposal. The 38i performed each of the eight cuts with only one notable technical difficulty. Internal stresses within the cylinder caused the 38 inch blade to get pinched near the end of the first parting cut. With support of an on-site machine shop, devices were constructed and used to relieve these stresses and free the blade. Once the first parting cut was performed, no other blade pinching was experienced.

Core Barrel

Three additional cuts were performed on the remaining sections of the core barrel with the C-HORCE. A special rigging device was used to remove the cut segments from within the core support assembly to the RMT work station. The thermal shield and core barrel were essentially concentric cylinders. The annulus space between the two cylinders was less than 1-inch. This made the use of commercially available plate clamps impossible. The projects engineers designed a rigging device to lift from the inside of the cylinder only. This device was built on site and lifted three core barrel cylinders to the RMT work station where the 38i reduced each cylinder to nine 40 degree segments. These segments totaling 33,800 pounds were then loaded to staged liners resulting in a weight based package efficiency of over 98%.

Thermal Shield

Sections of the thermal shield like the core barrel were cut using the C-HORCE. The three sections were each loaded on the RMT work station where the 38i reduced each cylinder to nine 40 degree segments. These sections totaling 33,200 pounds were then loaded to staged liners resulting in a weight based package efficiency of over 99%.

Lower Internals

The lower internals consisted of components of the RVI designed to provide support to the core. These components included the lower grid rib section, distributor plate, grid forging, outer ring, flow distributor, support posts and incore instrument guide tubes. Attached to this assembly were the remaining sections of the core barrel and thermal shield. This assembly weighed in at 80,600 pounds. Initially, the segmentation plan prescribed exclusive use of the RMT to volume reduce this large component. However, testing and documented performance demonstrated that the composite construction of the lower internals would likely result in RMT blade failure. Recognizing these limitation project engineers revised the segmentation plan to include partial dismantlement and development of another cutting tool.

This plan took advantage of the RMT's documented reliabilities and minimized its limitations. Long handled tools were used to remove the bolts that fastened the flow distributor. The flow distributor and the incore instrument guide tubes were removed from the lower internals

reducing the overall thickness of the assembly to less than 26-inches. The RMT was then used to cut this section into six segments. Meanwhile, the design, fabrication and testing of the 38i II (shown in Figure 4) was fast tracked in less than 12 weeks. This tool included the proven ability of two 38i blades on opposing towers resulting in a total cutting capacity of 26-inches. This tool also included a table to support and clamp the lower internal segments while cutting.



Fig. 4. 38i II installed in cavity.

The flow distributor was cut in half by the RMT and after removal of the hot ends of the incore instrument guide tubes was placed into two custom designed type 7A boxes making 16,700 pounds of Class A material available for immediate disposal. The remaining portions of the lower internals were processed by the RMT and 38i II into sections small enough for loading into ten CNS 8-120 hardware liners. Six of these liners were loaded with 35,400 pounds of Class B/C material while four were loaded with 28,500 pounds of Class A material.

RESULTS

All reactor internal components were segmented, packaged, and removed from the reactor building for shipment or storage by May 2006, allowing the reactor cavity to be drained and follow-on reactor segmentation activities to proceed in the dry state.

Area exposure rates at the work positions during the segmentation process were generally 1 mR per hr. Radiological exposure documented for the underwater segmentation processes totaled 13 Rem.

Two large reactor internal components weighing approximately 343,000 pounds were segmented into over 200 pieces for maximum shipping package efficiency and produced 5,600 lb of stainless steel chips and shavings which were packaged in void spaces of existing disposal containers, therefore creating no additional disposal volume. Table I outlines the package classifications.

Table I. SMUD Waste Package Classifications

Classification	Number of Packages	Total Weight
Class A	11 boxes	165,300 pounds
Class A	4 cask liners	28,500 pounds
Class B/C	17 cask liners	115,900 pounds
GTCC	1 storage container	33,300 pounds

Because no secondary waste was driven into suspension in the reactor cavity water, the water was free released after one pass through a charcoal bed and ion exchange filter system.

CONCLUSION

Mechanical cutting techniques are capable of underwater segmentation of highly radioactive components on a large scale. This method minimized radiological exposure and costly water cleanup while creating no secondary waste.