Decommissioning: Reactor Pressure Vessel Internals Segmentation

Technical Report

Decommissioning: Reactor Pressure Vessel Internals Segmentation

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REPORT SUMMARY

Decommissioning a nuclear plant covers a wide variety of challenging projects. One of the most challenging areas is the removal and disposal of the reactor pressure vessel (RPV) and the RPV internals. This report describes commercial reactor pressure vessel segmentation projects that have been completed and discusses several projects that are still in the planning stages. The report also covers lessons learned from each project.

Background
During decommissioning of a commercial nuclear facility, the reactor vessel and reactor vessel internals require special consideration. The high radionuclide content of these components generally requires them to be designated as Greater Than Class C (GTCC) radioactive material that is not suitable for near-surface disposal. South Carolina also has imposed a 50,000-curie limit on individual disposal shipments to Barnwell. The reactor vessel and reactor vessel internals, especially the core support baffle, may be a factor of ten times greater than this limit. For these reasons, reactor vessel internals must be carefully surveyed and, in most cases, cut into smaller pieces for temporary on-site storage or shipment to a burial facility.

Objective
To give utilities planning on RPV and internals removal and disposal the opportunity to carefully review lessons learned from those utilities that have recently preformed this task.

Approach
Researchers contacted utilities performing reactor pressure vessel internals segmentation. Information from each project was obtained and analyzed. Site visits also were made to a number of domestic utilities performing segmentation.

Results
Plasma arc, abrasive water jet, mechanical, electric discharge machining (EDM), and metal disintegration machining (MDM) have all been used to segment reactor vessel internals. Other methods—including the plasma saw and a laser cutting method—have been considered but have not been used to date. The most recent segmentation projects have used abrasive water jet cutting as the primary cutting method. The abrasive water jet operates in the range of 40,000 to 60,000 psi at flow rates of 5 to 8 gallons per minute. One disadvantage is the large amount of debris due to the abrasive grit material. Recycling of grit is generally not performed, and grit addition in the order of several pounds per minute is required. No matter which cutting method is selected, water clarity and water filtration are extremely important. Water clarity and water filtration may be the most troublesome aspects of underwater cutting. Maintaining and repairing the filtration system can require a considerable amount of effort and resources.

Two utilities were able to ship their entire RPV with internals to a burial facility. Both the Shippingport and Trojan reactor pressure vessels were filled with concrete grout and shipped to the U.S. Ecology low-level radioactive waste disposal facility at Hanford, Washington.

EPRI Perspective

As decommissioning efforts continue, RPV internals segmentation will remain a challenging task. The lessons learned from utilities performing segmentation will be valuable to those who need to perform segmentation in the future. This report describes major segmentation projects in the United States and Europe and describes lessons learned from each project. The work of these utilities demonstrates RPV internals segmentation can be performed safely and effectively.

Keywords

Decommissioning
Low-level waste
Reactor pressure vessel internals segmentation
Greater than class C waste
Independent spent fuel storage installation (ISFSI)
Abrasive water jet cutting

EXECUTIVE SUMMARY

The decommissioning of a nuclear plant covers a wide variety of challenging projects. One of the most challenging areas is the removal and disposal of the reactor pressure vessel (RPV) and the RPV internals. The purpose of the internals is to support the nuclear fuel, direct the flow of the reactor coolant, and provide shielding for the RPV. Due to the proximity to the nuclear fuel, the RPV internals become highly radioactive. The high radionuclide content of the internals generally require them to be considered as Greater Than Class C radioactive material that is not suitable for near-surface disposal. The reactor pressure vessel internals must be carefully surveyed and, in most cases, cut into smaller pieces for temporary on-site storage or shipment to a burial facility. In addition to the internals, several reactor pressure vessels have also been segmented prior to disposal.

The methods used to segment the RPV internals have included plasma arc, abrasive water jet, mechanical cutting, electric discharge machining (EDM), and metal disintegration machining (MDM). The majority of cutting on the reactor vessel internals has been done with plasma arc, abrasive water jet, or mechanical cutting methods. Each of these methods has advantages and disadvantages that must be weighed prior to selecting the most appropriate cutting method. The most recent segmentation projects have used abrasive water jet cutting as the primary cutting method. Specially designed filtration systems were used to remove the cutting fines and abrasive garnet used in the cutting process.

Table ES-1 provides a summary of the main RPV and RPV internals segmentation projects discussed in this report. The Shoreham, Yankee Nuclear Power Station, Shippingport, and Trojan RVP projects are complete. The Connecticut Yankee and Maine Yankee RPV internals segmentation projects are essentially complete. The Big Rock Point segmentation work is complete but the reactor pressure vessel is not scheduled to be removed until 2003. The San Onofre 1 segmentation project is scheduled to be completed in early 2002. In Europe, the BR-3 segmentation project is essentially complete while the other projects are still in progress.

Plasma arc cutting was the primary method of segmenting the RPV internals at Shoreham and the Yankee Nuclear Power Station. Abrasive water jet cutting was the primary method of RPV internals segmentation at Connecticut Yankee and Maine Yankee. At the BR-3 reactor in Belgium, two sets of RPV internals were segmented. A direct cutting comparison was performed on the thermal shield using plasma arc, electric discharge machining (EDM), and mechanical cutting. For the BR-3 thermal shield, mechanical cutting proved to be the most effective method.

Two utilities were able to ship the entire RPV with the internals to a burial facility. Both the Shippingport and Trojan reactor pressure vessels were filled with concrete grout and shipped to the US Ecology low level radioactive waste disposal facility at Hanford, Washington.

Utilities planning on RPV and internals segmentation need to carefully review the lessons learned from those utilities that have recently preformed this task. Segmentation lessons learned include minimizing the number of cuts, maximizing the size of the segmented pieces, and minimizing the amount of secondary waste generated. The filtration system used to maintain water clarity and remove cutting debris is extremely important in the overall success of the project. Although still a challenging task, RPV internals segmentation can be performed safely and effectively.

Table ES-1 Summary of RPV Internals Segmentation Projects

Plant	Start of Decomm.	RPV Internals	RPV	Disposal	Comments
Shoreham	1992	Segmented using plasma arc cutting	Segmented using mechanical cutting	Segmented RPV and internals shipped to Barnwell	RPV lower head left in place and decontaminated using zirconia grinding wheels
Yankee Nuclear Power Station	1993	Segmented using plasma arc cutting	Not segmented	RPV without internals and non GTCC waste shipped to Barnwell, GTCC waste stored on site	Total activity of RPV and internals was approximately 915,681 curies, RPV package without internals weighed approximately 325 tons and contained 4,800 curies
Connecticut Yankee	1996	Segmented using abrasive water jet cutting	Not segmented	GTCC waste stored on site, Plan to ship RPV to Barnwell	Activity of RPV and internals approximately 750,000 curies
Big Rock Point	1997	Segmented using plasma arc cutting	Not segmented	Plan to ship RPV to Barnwell	Internals segmentation completed, RPV removal scheduled for 2003
Maine Yankee	1997	Segmented using abrasive water jet cutting	Not segmented	Plan to ship RPV with limited internals and non GTCC waste to Barnwell, GTCC waste to be stored on site	Total RPV and internals activity estimated at 1,964,000 curies, RPV package for shipment to Barnwell estimated to weigh 900 tons and contain 49,000 curies
San Onofre 1	1999	Segmented using abrasive water jet cutting	Not segmented	Plan to ship RPV to disposal faciltiy. GTCC waste to be stored on site	Intenals segmentation scheduled for completion for early 2002
BR-3 Reactor	1991	Segmented two sets of RPV internals	Segmented using mechanical cutting	Plan to ship segmented RPV and internals to a disposal facility	Mechanical cutting of thermal shield shown to have advantages over EDM and plasma arc cutting
Shippingport	1983	Left intact	Left intact and filled with concrete grout	Shipped to Hanford	The RPV package weighed approximately 900 tons and contained 13,319 curies
Trojan	1995	Left intact	Left intact and filled with concrete grout	Shipped to Hanford	RPV package weighed approximately 930 tons and contained approximately 2,010,000 curies

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1
INTRODUCTION

During decommissioning of a commercial nuclear facility, the reactor vessel and reactor vessel internals require special consideration. The high radionuclide content of these components generally require them to be designated as Greater Than Class C (GTCC) radioactive material that is not suitable for near-surface disposal. The Code of Federal Regulations, 10 CFR 61, prevents Greater Than Class C material from being buried at a near-surface disposal site. In addition, the state of South Carolina has imposed a 50,000 curie limit on individual disposal shipments to Barnwell. The reactor vessel and reactor vessel internals, especially the core support baffle, may be a factor of ten times greater than the 50,000 curie limit. For these reasons, the reactor vessel internals must be carefully surveyed and, in most cases, cut into smaller pieces for temporary on-site storage or shipment to a burial facility. In several cases, the reactor pressure vessel was also segmented. This report describes commercial reactor pressure vessel internals segmentation projects that have been completed and discusses several projects that are still in the planning stages.

1.1 Waste Classification Issues

The whole reason for reactor vessel internals segmentation is the high radionuclide content of the internals. The Code of Federal Regulations 10 CFR 61.55 provides for three classes of radioactive waste destined for near-surface land disposal. This classification is based upon the presence and concentration of certain radionuclides. Waste characterization includes determining both the type and amount of individual radionuclides. The three classes of radioactive waste are designated as Class A, Class B, and Class C. The following descriptions are applicable for each classification.

Class A – Wastes that contain the lowest concentrations of radioactivity and only need to meet the minimum requirements on waste form and characteristics. If the waste is not stabilized, it must be segregated from Class B and C wastes at the disposal site.

Class B – Wastes that contain higher concentrations of radioactivity and must meet both the minimum and stability requirements on waste form and characteristics.

Class C – Waste that contain long-lived radionuclides and higher concentrations of radioactivity. These wastes must meet both minimum and stability requirements and also must be protected at the disposal site from inadvertent intrusion by deeper burial or other barriers.

Class A and B wastes can be buried without special provision for intrusion protection because they contain types and quantities of radioisotopes that will decay during the 100-year institutional control period and therefore do not pose an appreciable hazard to an intruder. Class

C wastes must be disposed so waste is at least five meters below land surface or disposal must incorporate intruder barriers that are designed to protect against inadvertent intrusion for at least 500 years.

The Code of Federal Regulations, 10 CFR 61.55, provides two tables to help classify radioactive waste. The first table provides concentration levels for longer-lived radionuclides while the second table provides concentration levels for shorter-lived radionuclides. Material that has a higher radionuclide content than allowed for Class C material is designated as Greater Than Class C material. The Low Level Radioactive Policy Amendment Act of 1985 gave the Department of Energy (DOE) the primary responsibility for developing a national strategy for the disposal of GTCC waste. The Department of Energy intends to eventually dispose of this waste along with spent nuclear fuel and high-level waste at a national disposal facility. Unfortunately, this disposal facility is not yet available. Further, the Department of Energy has not yet fully defined the waste acceptance criteria and the technical regulations for a disposal package of GTCC waste. Some utilities have opted to store this material in canisters that resemble nuclear fuel assemblies and store them in the stations spent fuel pool. Other utilities have elected to use larger canisters to reduce the amount of segmentation required. A number of utilities are attempting to remove their spent fuel from the spent fuel storage pool and store it an Independent Spent Fuel Storage Installation (ISFSI). The NRC has recently issued guidance that GTCC waste can be stored at a reactor site, including the cask storage pads of an Independent Spent Fuel Storage Installation (ISFSI), under a 10 CFR Part 50 license. (1) The GTCC waste must be stored in containers separate from the spent fuel storage casks and stored in a manner that meets the 10 CFR Part 20 regulations. The storage of the GTCC waste must pose no safety problems for licensed activities under 10 CFR parts 50 or 72. The NRC staff is also preparing a proposed rule to modify 10 CFR 72 to allow storage of GTCC waste in an ISFSI under the authority of a site-specific 10 CFR Part 72 license. This is an area in which the rules are changing and a utility in the process of decommissioning or contemplating decommissioning must stay actively involved.

1.2 Waste Disposal Issues

The Low-Level Radioactive Waste Policy Act enacted in 1980 and amended in 1985 was intended to provide a more equitable system for disposing of commercial low-level radioactive waste. This law provided that each state is responsible for the low-level waste generated within its borders and that the states may form compacts (groups of states) to manage the low-level wastes generated within the boundaries of the compact states. So far, a number of compacts have been formed, and reformed, but no new low-level waste disposal facility for a compact has been opened.

The options for low-level radioactive waste disposal in the United States are extremely limited. Only three sites currently accept low-level radioactive waste from commercial nuclear plants. These sites are near Richland, Washington, in central Utah, and near Barnwell, South Carolina.

The U.S. Ecology site near Richland, Washington is located on the U.S. Department of Energy's Hanford Reservation. This site is leased from the Department of Energy and operated by U.S. Ecology. The Hanford site accepts Class A, B and C low-level radioactive waste from the Northwest and Rocky Mountain Compacts. The Northwest Compact includes Alaska, Hawaii, Idaho, Montana, Oregon, Utah, Washington, and Wyoming. The Rocky Mountain Compact includes Colorado, Nevada, and New Mexico.

The Envirocare facility in Utah was initially set up to assist in the disposal of uranium mill tailings. In 1998, the Envirocare disposal facility began accepting Class A low-level radioactive waste. This facility is open to low-level waste generators from all states. In addition, the Envirocare facility has a license to accept “mixed waste.” Mixed waste contains both radioactive and hazardous material waste components.

The Barnwell low-level radioactive waste disposal site is owned by the State of South Carolina and operated by Chem-Nuclear Services, a wholly owned subsidiary of GTS Duratek. Barnwell was opened during the early 1970’s and has accepted the majority of the commercial low-level radioactive waste that has been shipped for disposal. Barnwell has had a number of “closure plans” and the rules for radioactive waste shipments to Barnwell have changed over the years. In 1995, the State of South Carolina enacted legislation that changed the rules once again. Barnwell could accept waste from generators in all states except North Carolina and the Northwest Compact. North Carolina was restricted from use of the site due to its failure to develop a disposal facility to replace Barnwell. The Northwest Compact states were to use the Hanford facility. South Carolina withdrew from the Southeast Compact and joined a new Atlantic Compact that included Connecticut and New Jersey. The current plans call for Barnwell to except limited low-level radioactive waste shipments from all the “approved “ states through 2008. After 2008, Barnwell is to accept only low-level waste generated from states within the Atlantic Compact.

The shipment of low-level radioactive waste is another area in which the rules have changed. Again, a utility in the process of decommissioning or contemplating decommissioning must stay actively involved in order to determine the current options.

1.3 Reactor Vessel Internals Cutting Issues

If the reactor vessel internals must be cut due to waste disposal considerations, what is the best method of cutting? Like most issues, there is not one definitive answer. A number of cutting techniques have been used. Plasma arc, abrasive water jet, mechanical, electric discharge machining (EDM), and metal disintegration machining (MDM) have all been used to segment reactor vessel internals. Other methods including the plasma saw and a laser cutting method have been considered but have not been used to date. Table 1-1 prepared by Duke Engineering and Services provides a listing of the potential benefits and disadvantages with each of these cutting methods (2). The majority of cutting on reactor vessel internals has been done with plasma arc, abrasive water jet, or mechanical methods. Plasma arc cutting is relatively fast and can be adapted to computer controlled machining. The disadvantages include the large amount of energy required for the plasma arc and the fine debris that can cause contamination and cleanup problems. This molten residual material due thermal cutting is known as dross while residual material due to non-thermal cutting is known as swarf. Plasma arc gases can obscure visibility while cutting and a gas collection and disposal system is generally required. The maximum thickness for underwater plasma arc cutting is approximately 4 inches while the maximum water depth for this method is approximately 35 feet.

The abrasive water jet cutting is not quite as fast as the plasma cutting but requires less energy. The abrasive water jet operates in the range of 40,000 to 60,000 psi at flow rates of 5 to 8 gallons per minute. One disadvantage is the large amount of debris due to the abrasive grit material. Recycling of the grit is generally not performed and grit addition in the order of several pounds per minute is required.

Mechanical cutting means are generally slower than the plasma arc or abrasive water jet cutting. Specially designed circular and band saws have been developed for underwater cutting. One disadvantage of mechanical cutting has been the high equipment maintenance needed including frequent replacement of the cutting blades.

EDM and MDM cutting have been used for special applications requiring more precise cutting or cutting at greater water depths. Disadvantages with both these methods include the slow cutting speeds and the very fine debris that can cause contamination and cleanup problems. Other methods such as the plasma saw and laser cutting are still in the experimental stage as far as RPV internals cutting is concerned.

No matter which cutting method is selected, water clarity and water filtration are extremely important. Water clarity and water filtration may be the most troublesome aspects of underwater cutting. Although filtration system designs may vary, the filtration system generally includes a 1,500 to 2,000 gpm high capacity cyclone separator, a multi stage filtration process, and a demineralizer. Maintenance and repair of the filtration system can require a considerable amount of effort and resources.

Each of the RPV internals segmentation methods has some benefits and some disadvantages. These must be weighed and evaluated prior to determining the most appropriate cutting method. The method selected is usually most dependent upon cost and schedule. Other considerations generally include ALARA concerns, debris management, and the reliability and projected maintenance of the equipment. The most recent segmentation projects have use abrasive water jet cutting as the primary cutting method.

Table 1-1
Reactor Vessel Internals Cutting Methods

Cutting Method	Description	Benefits	Disadvantages
Plasma Arc	High temperature, high velocity jet metal melt, Displaces metal in path	Fast cutting, Adaptable to computer controlled machining	Requires conductive material, Requires large amounts of energy, Creates fine debris that can causes contamination and cleanup problems, High energy increases soluble radioactivity
Abrasive Water Jet (AWJ)	Entrained abrasive material in high energy water jet	Medium speed cutting, Suitable for all materials	High amount of debris due to the abrasive material
Mechanical	Standard milling, drilling and sawing techniques	Cutting fines are larger and easier to filter, Well established technique	Slower cutting, High equipment maintenance
Electric Discharge Machining (EDM)	Metal separation through electrical discharge	Capable of remote handling (under greater water depths)	Slower cutting, Cutting material is extremely fine which causes contamination and cleanup problems
Metal Disintegration Machining (MDM)	Metal separation through electrical discharge	Capable of remote handling (under greater water depths)	Slower cutting, Cutting material is extremely fine which causes contamination and cleanup problems
Plasma Saw	Resembles mechanical saw but uses EDM as the cutting mechanism	Very fast cutting	Very limited experience (experimental), Requires high amounts of energy, Cutting material is extremely fine which causes contamination and cleanup problems
Laser	High intensity energy beam	Clean, Fast	Experimental

2 UNITED STATES EXPERIENCE

2.1 Shoreham

Shoreham was the first large commercial nuclear power facility to be decommissioned in the United States. The project occurred during a time of evolution of the Nuclear Regulatory Commission's (NRC) regulation and oversight of commercial nuclear facility decommissioning. Shoreham essentially served as a "test bed" for emerging NRC policy and regulations. (3)

The Shoreham facility was an 848 MWe boiling water reactor constructed by Long Island Lighting Company. Shoreham achieved initial criticality in February 1985. Low power testing was authorized by the NRC in July 1985 and was conducted intermittently until June 1987 when the plant was shut down in accordance with an agreement with the State of New York due to emergency response and evacuation issues. The facility was operated for less than two effective full power days, at power levels less than or equal to five percent power. Planning for decommissioning began after shutdown and in 1992 the plant and 11 acres were transferred to the Long Island Power Authority to complete decommissioning. Not including the nuclear fuel, control rod blades, and other readily removable nuclear reactor assembly items, the total radioactive inventory was calculated to be approximately 602 curies. The radioactivity was almost all in-situ neutron activation products confined to the reactor pressure vessel, the reactor pressure vessel internals and the biological shield wall. The personnel radiation exposure for the entire decommissioning project was approximately 3.2 person-rem. The personnel radiation exposure for the reactor vessel and internals segmentation and removal was approximately six-tenths of a person-rem.

A number of contractors were assembled to provide decommissioning support. The primary contractors and their support areas are listed below.

- UEC Catalytic Inc. - General contractor services, craft support
- Power Cutting Inc. - Segmentation of reactor vessel internals
- E.H. Wachs Co. - Reactor pressure vessel segmentation and removal
- Trentec Inc. - Removal of reactor biological shield wall
- Scientific Ecology Group Inc. - Radioactive material volume reduction

The reactor pressure vessel and internals were decontaminated to the extent practicable while in place by water flushing and were then segmented. The reactor vessel internals were segmented using semi-automatic plasma arc cutting equipment. The reactor pressure vessel, except for the lower head and reactor vessel nozzles, were segmented using mechanical cutting means. The reactor pressure vessel was severed into shell sections using a platform mounted rotary mounted mechanical cutting machine from the inside of the vessel. The shell sections were then cut by plasma arc into appropriately sized pieces for efficient handling, packing, and shipping. The reactor vessel lower head was left in place and decontaminated using abrasive surface grinding. The decontamination was performed using seven inch zirconia grinding wheels. This effort required approximately 7,500 man hours to remove up to 12 mils of stainless steel cladding over a surface area of 1,500 square feet.

The total decommissioning costs were reported to be $180.6 million. The reactor pressure vessel and internals segmentation and removal accounted for approximately $10 million of this total. The decommissioning was completed with the final Shoreham Termination Survey conducted in November 1994. Lessons learned from the Shoreham decommissioning included the following.

- A constructive dialog between the utility and the NRC Staff was established early in the project in order to discuss and resolve numerous questions and open issues. This allowed for early identification of problems and potential problem areas and often resulted in their early resolution.
- Project costs were strongly influenced by staffing levels. Maintenance of scheduled completion dates and tying staffing levels closely to specific milestones is recommended as a means to control costs.
- Proven processes were strongly favored over new and untried approaches for the plant system dismantlement and component segmentation.
- A contribution to success of the decommissioning was selection of contractors with proven track records for critical processes such as RPV segmentation and removal. Bid specifications for such work should be carefully prepared to ensure that only those firms with successful experience in very similar work are qualified as bidders.

Although the Shoreham facility was only initially slightly radioactive, the experience and lessons learned from Shoreham are applicable to subsequent decommissioning projects.

2.2 Yankee Nuclear Power Station

Yankee Nuclear Power Station (YNPS) was a 185 MWe PWR operated by Yankee Atomic Electric Company (YAEC) and located in Rowe, Massachusetts. Yankee was the third commercial power station licensed in the United States and began commercial operation in late 1960. Yankee and had a lifetime capacity factor of 74 percent. In 1992 the Board of Directors voted to end power operation and begin decommissioning. The decision was based upon the high costs associated with resolving reactor vessel embrittlement issues and the relatively low demand for electricity in the New England region at that time. Yankee personnel reviewed the options for radioactive waste disposal. South Carolina had recently announced their decision to extend access to Barnwell's waste disposal facilities to out-of-compact states through June, 1994. (In 1995 access was extended until 2008.) Due to the Barwell extension, Yankee personnel initiated an immediate program to remove reactor internals, steam generators, and pressurizer and ship as much material as possible to Barnwell. The Yankee goal was immediate dismantlement with the objective of returning the site to a "green field." Yankee acted as its own prime contractor and maintained control and oversight of the decommissioning activities.

A major element of the initial component removal program was the segmentation of the reactor vessel internals (4,5). This effort included developing a segmentation plan, writing procedures, and developing a waste packaging and shipping plan. The development, testing, and qualification of segmentation equipment, as well as control of cutting debris and off-gas byproducts was included in the segmentation and packaging plans. A team of experienced Yankee personnel was assembled to perform this work. The Yankee personnel also relied on outside expertise to help with the planning and actual segmentation. The following companies supported the Yankee team:

- Chem Nuclear Services Inc. (CNSI): packaging, transport, and disposal support.
- WMG, Inc.: reactor internals characterization, packaging plan development, and documentation of waste shipments.
- PCI Energy Services: planning, procedures, debris collection, and segmentation tooling and personnel.

2.2.1 Internals

The primary function of the reactor internals is to support the core components, direct the flow of the reactor coolant, and provide shielding of the reactor vessel. Following the Yankee shutdown, the fuel, control rods and source elements were removed from the vessel. The Yankee reactor internals, shown in Figure 2-1, were bolted together into three subassemblies. These were the Thermal Shield, the Lower Core Support Assembly, and the Upper Core Support Assembly. The Upper and Lower Core Support Assemblies were removable. The Thermal Shield was initially assembled by bolting together cylindrical sections within the vessel and was not easily removable. All of the components were fabricated from type 304 Stainless Steel. Table 2-1 lists the reactor vessel internal components and their estimated curie content. The total curie content was estimated at 915,681 curies. The component removal plan was to segment the internals into smaller sections that could be placed into commercially available irradiated hardware transport casks for transport to Barnwell. The plan identified that only the Core Baffle would have to be treated as Greater Than Class C waste and remain on site. The RPV was to be filled with concrete grout and also shipped to Barnwell.

2.2.2 Packing Plan

The operating history of the 21 different cores in the Yankee reactor was used to develop the flux history, resultant raionuclides, and curie content for each of the components listed in Table 2-1. The packaging plan used the radionuclide profile to determine the transport cask requirements. Blending of the reactor vessel internals components was used to balance the curie content and minimize the number of shipments required. Segmented pieces were placed in steel liners and loaded into the transport casks for shipping. At the Barnwell disposal site, the liners were removed and readied for burial. The transport casks were then returned to Yankee to receive additional liners filled with radioactive segmented pieces. This process was repeated until the project was completed.

2.2.3 Site Preparation

While the segmentation systems were being designed and fabricated, a considerable effort was underway at the Yankee site to prepare for the project. The flooded Shield Tank Cavity normally provided shielding for transferring fuel assemblies to and from the reactor vessel and was determined to be the best location for the segmentation work. All material in the shield tank cavity not needed for the segmentation project was removed. In order to present any cavity leakage, the inflatable seal normally used between the reactor vessel and shield tank cavity floor was replaced with a welded seal. The cables which previously supplied power to two of the main reactor coolant pumps were rerouted to create two switchboards, each capable of supplying 480 volt, 600 amp three-phase AC power for the Plasma Arc Cutting system. The existing refueling manipulator bridge was disassembled which required relocation of some control panels needed for handling canisters containing Greater Than Class C waste.

2.2.4 Segmentation and Support Systems

Plasma Arc Cutting was chosen as the primary means of segmenting the internals because of its proven reliability and speed. The plasma arc jet quickly melts and displaces the reactor vessel internals material in its path.

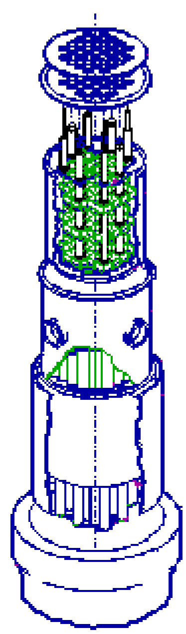

Figure 2-1
Yankee Nuclear Power Station RPV Internals

Table 2-1
Yankee Reactor Pressure Vessel Internal Components

Component	Weight lbs.	Curies
Control Rod Drive Shaft (24)	2,740	9
Core Holddown Spring	1,000	1
Guide Tube Holddown Plate	1,970	1
Guide Tube Support Plate	2,740	3
Guide Tube Assemblies (24)	6,910	3
Instrumentation Assembly	10,645	146
Upper Core Support Barrel	9,470	296
Upper Core Support Plate	6,490	15,300
Lower Core Support Barrel	11,960	4,200
Secondary Core Support (4)	1,875	1,410
Thermal Shield Clamp	3,010	1,400
Thermal Shield	39,485	17,700
Core Barrel	10,485	52,100
Core Baffle	8,160	792,336
Lower Core Support Plate	6,065	29,100
Core Radial Support	835	36
Shroud Top Plates (4)	1,405	1,520
Shroud Tubes(4)	3,230	76
Shroud Lower Tie Plate	1,910	9
TOTALS	**130,385**	**915,681**

The plasma arc process used was capable of cutting 4 inch thick stainless steel and extending (telescoping) to a water depth of 25 feet. The reactor vessel internals were removed from the reactor vessel and cut on a specially designed cutting platform in the flooded Shield Tank Cavity.

After the Upper and Lower Core Support assemblies were removed, the thermal shield was removed using metal disintegration machining (MDM). The thermal shield was removed by boring out the bolts holding the vertical sections together. MDM was used because of the greater underwater depth and the difficult to access bolt locations. While significantly slower than Plasma Arc Cutting, MDM could work effectively in the increased water depth of the lower thermal shield bolt locations. Each section of the thermal shield was removed from the reactor vessel and brought to the cutting platform for further cutting with the plasma arc system.

The plasma arc cutting was guided by a computer controlled multi-axis system. The computer controlled system was housed on a new manipulator bridge which ran on the rails of the old refueling manipulator bridge. The manipulator controlled movement of the plasma arc torch in three translational and one rotational axis.

Several methods were used to control the cutting debris. The cutting was done on a specially designed cutting table. The cutting table consisted of open lattice beams mounted on legs sitting on the shield tank cavity floor. The table had four high sides, one of which was hinged to allow side entry of the components to be cut. A cross flow jet was used to capture debris that fell through the lattice beams. The jet flow was then filtered through a debris collection system. Heavier debris that passed through the collection flow was funneled into a collection canister. In addition, water filtration and ion exchange units were used to continuously purify the cavity water to help with water clarity and reduce water radioactivity levels. A hood was floated over the cutting table whenever plasma cutting was taking place to collect the gases generated by the cutting. High efficiency particulate air (HEPA) filters were used to filter the gas collected by the hood. The filtered gas was then discharged into the containment air purge system where it was monitored for airborne contamination.

The actual segmentation began in October 1993 with the first pass of the plasma torch over the guide tube holddown plate. Segmentation took place during each day with cask loading and handling occurring during the evening. Most of the work was done on a basis of two 10 hour shifts per day. After each component was brought to the cutting station, it was then segmented, weighed, dose profiled, and then moved to its designated shipping liner. The weight and dose profiles were used to verify the estimates and keep a continuous inventory of the material in each liner. Periodic corrections were made to the packaging and segmentation plans based on the actual data. The following is a compilation of the component segmentation data:

- A total of 19 subassemblies, plus the plasma cutting table, were characterixed and segmented
- Approximately 2,000 cuts were made
- Approximately 3,200 linear feet of material was cut
- Approximately 1,420 pieces were segmented and handled

The final cask shipment was made in June 1994 and approximately 123,000 curies were shipped off site. The remaining material was packed and stored on-site as Greater Than Class C waste.

2.2.5 Packing and Shipping

Three types of casks were chosen from those available from Chem Nuclear Systems at the time of the project. The CNS 8-120A cask was designed for mildly activated material. The CNS 8-120B cask was designed for higher concentrations of radionuclides. Both casks have a wall thickness equivalent to 4.5 inches of lead and an internal cylindrical volume of 62 inches in diameter by 75 inches in length. The third cask, the CSN 3-55 cask, is a high radiation, low volume cask with a wall thickness equivalent to 7 inches of lead. This cask has an internal cylindrical volume of 36 inches in diameter by 117 inches in length.

The segmentation plan outlined the method and sequence each component was to be cut. In order to avoid contamination of slightly activated material by debris from highly activated material, the segmentation generally proceeded in increasing order of material activation. Table 2-2 provides a summary of the casks used in the material shipments.

Table 2-2
Summary of Yankee Radioactive Material Shipments

Type of Cask	Principal Material	Number of Shipments
3-55	Irradiated Hardware	17
3-55	Segmentation Tooling	1
8-120	Irradiated Hardware	7
8-120	Segmentation Tooling	2
8-120	Filters	6
8-120	Resins	1
Other	Filters	2
Total		**36**

The core baffle contained approximately 86% of the reactor vessel internal's radionuclide content and 6% of the reactor vessel internal's volume. Due to the high radionuclide content, the core baffle was segmented and treated as Greater Than Class C waste. The segmented baffle was packaged in containers designed to meet existing site seismic requirements and configured similarly to a Yankee fuel assembly. The exterior dimensions of the package were approximately 7 inches square and 9 feet in length. (6) The top end fitting was designed to be bolted to the container body after loading the core baffle segments. The top end fitting was also designed so the container could be handled using either an existing fuel handling tool or a sling and hook. The bottom end fittings were designed similar to a fuel assembly to allow storage in the spent fuel racks. A total of 25 Greater Than Class C containers were loaded. Sixteen of these containers were loaded with core baffle pieces and nine containers with cutting debris and bag filters. The containers were moved to the spent fuel pool and dose rate profiles were taken on each container. Approximately 793,000 curies were packaged in the 25 containers and stored on site in the spent fuel pool as Greater Than Class C waste.

With the internals removed, the reactor pressure vessel was removed and packaged in a 3 inch thick steel cask for shipment and disposal at Barnwell. The reactor pressure vessel was approximately 10 feet in diameter and 28 feet long and contained approximately 5,500 curies. The reactor pressure vessel was filled with low-density concrete grout prior to shipping. The annulus between the reactor pressure vessel and steel cask was filled with normal density concrete grout. The reactor pressure vessel package was licensed as an NRC 10 CFR 71 equivalent package. The total package weighed approximately 325 tons. In 1997, the package was transported to Barnwell via heavy hauler and special rail car for final disposal.

2.2.6 Lessons Learned

Lessons learned from the Yankee segmentation project included the following:

- Flexibility is needed to modify packaging and segmentation plans to meet changing conditions.
- Segmentation in the order of the least irradiated to the most irradiated components decreases the potential for cross contamination.
- The material handling times greatly exceed the segmentation times.
- Improvements are needed in the control of plasma arc cutting debris.
- The design change process used during plant operation can also be used for the decommissioning process.
- The latest radionuclide analysis codes should be used and normalized to empirical data in order to increase the calculation accuracy.

2.3 Connecticut Yankee

Connecticut Yankee was a 590 MWe pressurized water reactor operated by Northeast Utilities. The unit began commercial operation in 1968 was shut down in 1996 due to economic considerations. Decommissioning activities began shortly after the unit was shut down and in April 1999 Bechtel was awarded a fixed price contract to complete the decommissioning. The reported overall cost for the entire decommissioning was approximately $550 million.

The program to segment the reactor vessel internals was undertaken to prepare the reactor vessel for removal, transport and disposal. The most radioactive reactor vessel internal components, the core barrel and core support baffle, were estimated to contain approximately 750,000 curies (7). The reactor pressure vessel configuration before segmentation is shown in Figure 2-2. The irradiated core baffle prior to segmentation is shown in Figure 2-3. The main segmentation considerations included worker exposure, airborne contamination and control, waste form and disposal costs, cavity cleanup requirements, and the overall schedule. The majority of the segmentation was performed using an abrasive water jet. Garnet was used as the abrasive media. Metal discharge machining (MDM) was used to remove the lower core support plate bolts and to remove bolts from the upper internals. The segmented components were placed in sixty-four fuel like containers to be stored in the spent fuel pool and eventually to be placed in an interim spent fuel storage facility. The working area above the cavity pool is shown in Figure 2-4. A compilation of the component segmentation data is provided below:

- Approximately eighteen to twenty month project duration
- Approximately 750,000 curies removed
- Approximately 1,800 linear feet of material were cut
- Approximately 600 pieces were cut
- Sixty-four fuel-like canisters were loaded and stored on site
- Personnel exposure was approximately 177 man-rem
- Approximately 400 to 500 cubic feet of cutting debris
- Approximately 600 cubic feet of filters and resin

A debris collection and filtration system was used to capture the cutting debris and maintain water clarity. The cutting was done on a specially designed cutting table to segregate the cutting operations from the rest of the cavity. The debris collection and filtration system consisted of a cyclone separator, back flushable filters, an ion exchange vessel and a debris collection vessel. The underwater filtration system is shown in Figure 2-5.

Key safety considerations in the segmentation process included prevention of any inadvertent removal from the cavity of any highly activated components, contamination control, and control of airborne contamination. Other safety considerations were providing adequate shielding and the hazard of working near and over the cavity pool. The main project challenges included maintaining equipment reliability, high dose rates over the segmentation table, and material collecting on the segmentation curtain and sides of the reactor cavity. Other challenges included the reduction in cavity clarity during the cutting operations and difficulty placing the segmented pieces into the fuel-like storage canisters.

The radiation exposure exceeded the pre-job estimates primarily due to underestimating the complexity of the segmentation activities. The current exposure estimate for the segmentation process is 177 person-rem. During the segmentation process a number of exposure reduction initiatives were incorporated. These reduction initiatives included additional shielding of the bridge area, frequent use of high pressure washdowns, additional component shielding, and the establishment of a low dose waiting area.

The segmentation demobilization effort was also quite extensive. The primary demobilization effort included removing the segmentation table, removal of the filtration skid, and removal and packing of the cutting debris. Other demobilization activities included an extensive cavity cleanup, removal of the filters and charcoal media, and removal and cleanup of miscellaneous tools and equipment. The cavity cleanup has been a problem and final cleanup will not be completed until the end of 2001. The final configuration of the reactor pressure vessel after the segmentation is shown in Figure 2-6. The reactor pressure vessel is scheduled to be shipped to Barnwell in 2002.

Lessons learned from the Conneticut Yankee segmentation included the following:

- Minimize the amount of cutting and maximize the size of the remaining pieces.
- Carefully evaluate the reliability of the cutting equipment and the ease of performing maintenance on the equipment.
- Integrate the radwaste disposal and demobilization plans into the segmentation project.
- Minimize the time spent working over the cavity pool.

A number of utility decommissioning personnel visited the Connecticut Yankee site and lessons learned from the Connecticut Yankee segmentation were very beneficial to subsequent segmentation projects.

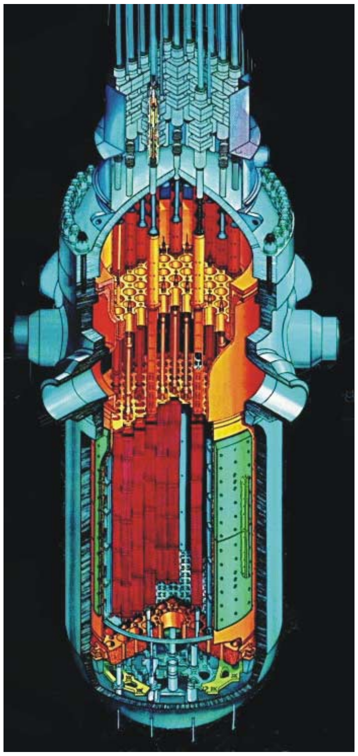

Figure 2-2
Connecticut Yankee RPV Configuration

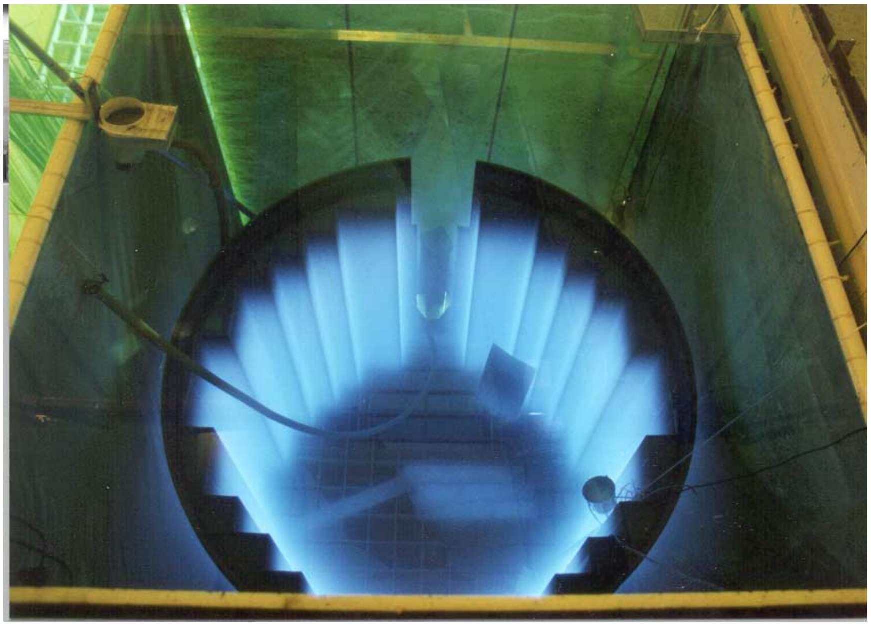

Figure 2-3
Connecticut Yankee Irradiated Core Baffle

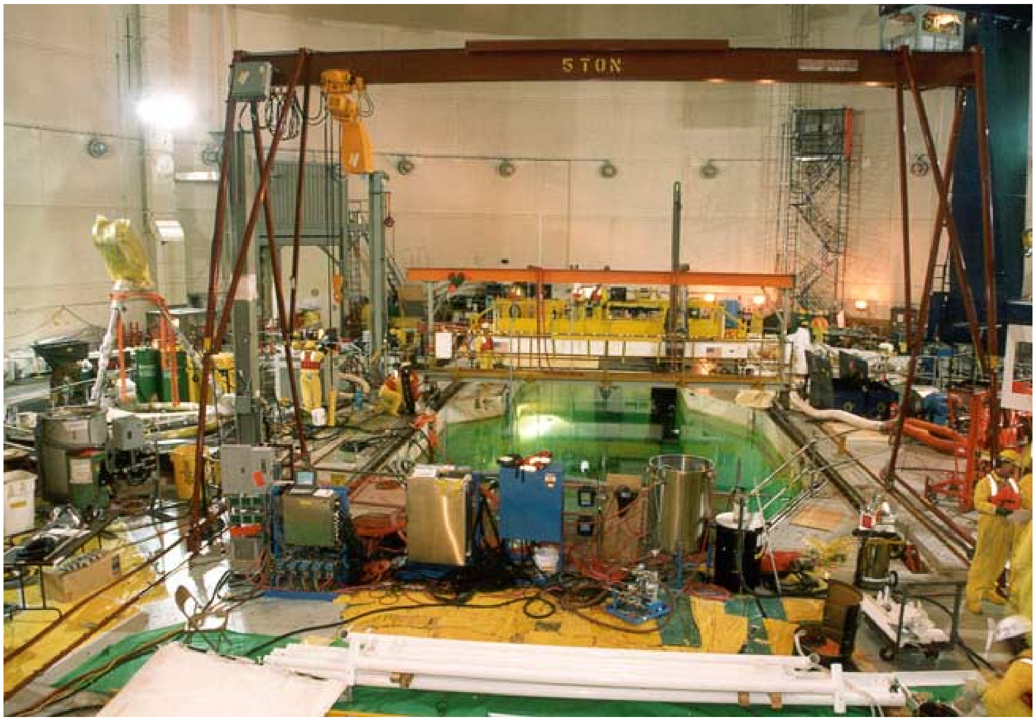

Figure 2-4
Connecticut Yankee Segmentation Area Above Cavity Pool

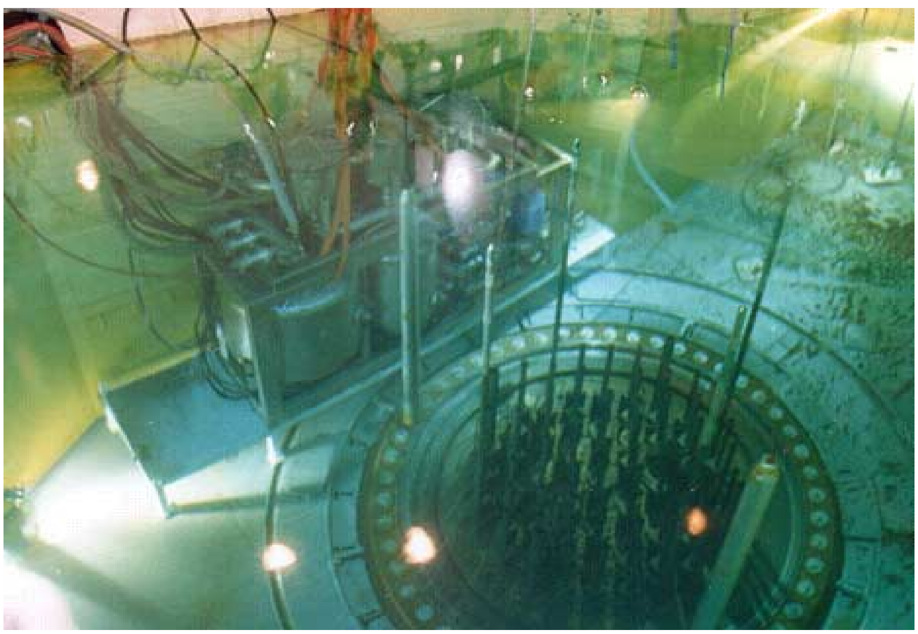

Figure 2-5
Connecticut Yankee Underwater Filtration System

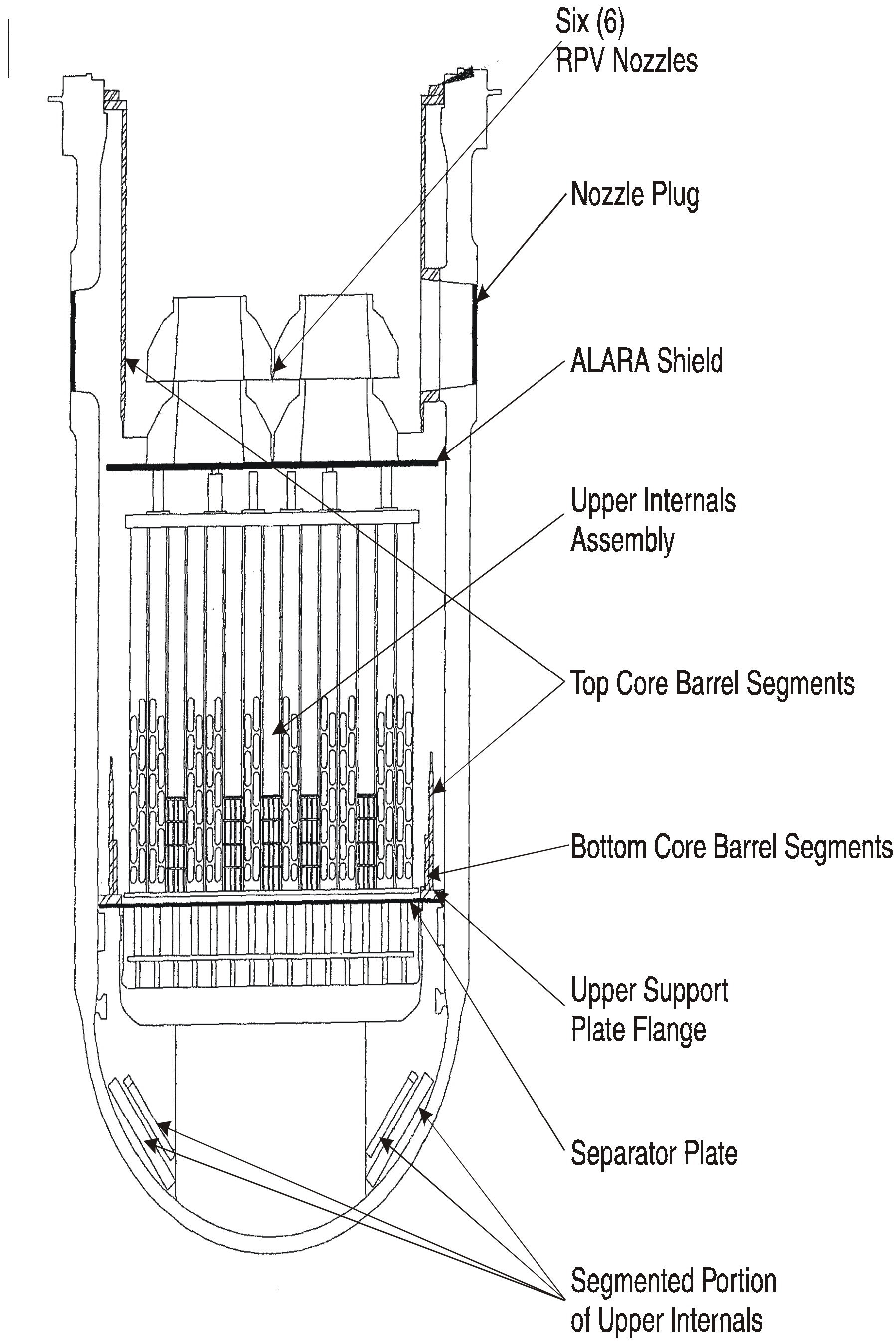

Figure 2-6
Connecticut Yankee RPV Configuration after Segmentation

2.4 Big Rock Point

Big Rock Point was a 67 MWe BWR owned by Consumers Energy. Big Rock Point began commercial operation in 1965 and was shut down in August 1997. Since the shutdown work has been initiated to restore the 600-acre site to a green field. A primary system chemical decontamination was performed early in 1998 using EPRI's DfD process. Six hot DfD cycles were applied along with a 70 hour ambient temperature DfD cycle. Approximately 406 curies of gamma-emitting activity were removed and final average dose rates of less than or equal to 10 mR/hr were achieved.

Because of the relatively small size of the Big rock Point core, the majority of the RPV internals could remain in the RPV and not exceed the 50,000 curie limit imposed by Barnwell. Table 2-3 shows the estimated curie content of the RPV and some of the RPV internals.

Table 2-3
Big Rock Point Estimated Radionulcide Activity

Component	Extimated Activity (curies)
Top Guide Plate	538
Top Guide Stubs	1500
Seal Housing	66
Thermal Shield and Retainer	3830
Seal Weights	589
Reactor Pressure Vessel	282

The segmentation of the RPV internals included the removal the reactor vessel grid bars. The grid bars were cut with an underwater hydraulic mill saw operating at low rpm. Other pieces were removed and segmented in the spent fuel pool using a crusher/shearer that was versatile enough to cut up channel assemblies, control rod drive blades, incore instruments, and other miscellaneous items. The steam drum was cut free from all of its piping. The steam drum nozzles were cut using a mechanical clamp-on hydraulic cutter. The reactor pressure vessel nozzles were cut free using the same hydraulic cutter. The reactor pressure vessel penetrations will be capped and the RPV again filled with water for shielding purposes until removal from the containment building.

One of the challenges to the RPV internals segmentation was lack of sufficient room in the spent fuel pool to process waste. After removal of the fuel from the RPV, the spent fuel pool was entirely filled. One of the major activities was to clean up the spent fuel pool. The spent fuel pool cleanout was considered to be the largest and most ambitious pool cleanout project to date. The project included characterization, volume reduction, packing, classification, and shipment of irradiated hardware. Working in the spent fuel pool required very detailed planning. The fuel cleanup project was performed from January 1999 to May 2000 by Nukem Nuclear

Technologies. The irradiated hardware that was processed included control rod blades, channel assemblies, incore detectors, coupon racks, and flow orifices. The principal tool that was used to cut the components was a crusher/shearer that was versatile enough to cut a number of different components. The majority of the segmented pieces were placed in special shipping casks. A total of nineteen cask shipments were made to Barnwell for final disposal. Greater Than Class C material remaining in the spent fuel pool will be loaded into a dry fuel canister and placed in an on site Independent Spent Fuel Storage Installation (ISFSI).

Lessons learned to date on the Big Rock Point project include the following:

- Minimize the number of plant personnel to support the project.
- Dry runs and equipment testing proved to be very beneficial especially when dealing with new equipment and limited work areas.

The current schedule calls for the reactor pressure vessel to be removed from the containment, filled with concrete grout, and placed in a special container for shipment to Barnwell in 2003 for final disposal.

2.5 Maine Yankee

Maine Yankee was an 864 MWe PWR owned by Maine Yankee Atomic Power Co. and several other utilities. The unit began operation in 1972 and was shut down in August 1997 for economic considerations. Maine Yankee initially selected Stone & Webster to be the decommissioning operations contractor and, after a period of time, decided to take back control of the decommissioning activities.

The segmentation of the reactor vessel internals was performed by abrasive water jet and mechanical cutting by Framatome ANP. (8) The initial cutting activities began in November 2000 and are projected to be completed during the summer of 2001. An initial estimate of the weight and activity associated with the Maine Yankee reactor vessel and reactor vessel internals is listed in Table 2-4. The projected dose for the entire segmentation project is 57 person-rem.

Table 2-4
Estimated Maine Yankee RPV Internals Segmentation

	Shipped in RPV	Shipped in Casks (3-55s)	Stored in ISFSI	Total
Weight	70%	20%	10%	363,000 (lbs)
Activity	2%	15%	83%	1,964,000 (Ci)

The RPV internals segmentation was performed in the flooded refueling cavity. Cavity penetrations were sealed to confine the cutting debris to the reactor cavity. Bolt holes and crevices in the reactor cavity were sealed prior to flooding to minimize any potential crud traps. Reactor cavity housekeeping and contamination controls were strictly maintained to prevent buildup of high dose sources. A checklist of requirements was developed for Radiation Protection technicians to follow to ensure all procedural and ALARA requirements were met. A dedicated Radiation Protection staff was maintained throughout the segmentation project.

Extensive predeployment planning, simulation, and testing were performed prior to any on-site segmentation work. The reactor pressure vessel and internals were modeled in a 3-dimension CAD-CAM software package. Each cut was preplanned and computer simulated as well as the storage of the segmented pieces in the RPV and GTCC waste containers. This computer simulation identified and helped mitigate a number of high risk factors. A cut away view of the reactor pressure vessel and internals prior to any segmentation is shown in Figure 2-7. The planned cuts on the thermal shield and core support barrel are shown in Figure 2-8.

The segmentation performed by Framatome ANP was done with abrasive water jet and mechanical cutting. No thermal cutting (plasma arc, EDM, or MDM) was performed. The cold cutting methods provided a significant reduction in the projected overall personnel exposure. In order to minimize cross contamination, the cutting was performed first on the least activated components and progressed to cutting the most highly activated components.

The abrasive water jet cutting was performed with a 4 axial telerobotic manipulator that was remotely operated. Custom designed and fabricated rigging equipment was used to assist in the lifting and positioning of the internals and is shown in Figure 2-9. A cut away view of the lower support structure with the custom rigging and lifting equipment is shown in Figure 2-10. The rigging equipment was also used to handle larger segmented pieces as shown in Figure 2-11. A number of other innovations were developed during the segmentation process. These innovations included vision enhancement during the abrasive water jet cutting, an abrasive feed assist system, capture of the cutting waste, and a new licensed waste container for the high level abrasive swarf.

Probably the most difficult challenge in the entire segmentation process was the removal of the colloidal suspension created from the fragmentation of the garnet used in the abrasive water jet cutting. Initial testing demonstrated that a simple filtration system quickly clogged. A specially designed and patented filtration system was fabricated for the actual water jet cutting operations. This Solid Waste Collection System (SWCA) was used in conjunction with a separate Cavity Water Treatment System (CWTS) in order to control debris cleanup and water clarity. Another challenge was an initial CRUD burst from the residual primary system decontamination waste due to incomplete flushing of the system after decontamination. The reliability and maintenance of the submerged system was also challenging and minimizing the secondary waste volume was a continual effort.

Maine Yankee decided to use larger than fuel assembly sized containers for their GTCC waste in order to significantly reduce the number of cuts that had to be performed. These waste containers are sized to hold 24 fuel assemblies. Each waste container will hold two cylindrical canisters approximately 6 feet in diameter and 8 feet tall. Two canisters containing GTCC waste will be stacked on top of each other in one waste container. Four waste containers with GTCC waste and sixty waste containers with spent fuel will be stored in the on-site Independent Spent Fuel Storage Installation (ISFSI). The RPV containing a portion of the segmented internals will be shipped to Barnwell for permanent disposal in 2002.

Lessons learned form the Maine Yankee segmentation included the following:

- Teamwork and communications between all workgroups is necessary for key evolutions.
- Continuous monitoring of waste debris accumulating in the high integrity containers requires multiple survey points to ensure shipping dose rates of the casts are not exceeded. Additional remote monitoring detectors were installed on the high integrity container liners throughout the project.
- The use of a remotely operated capping tool to install lids on the high integrity container liners would help reduce exposure.
- Design improvements are needed to enhance the vacuuming and debris removal operational efficiency
- Waste collection, processing, and waste packaging are critical elements for a successful project
- Modular and quick disconnect design features are needed for all submerged systems
- A complete flush and verification of the primary loop cleanliness after the primary loop decontamination was needed
- Waste collection, processing, and waste packaging are critical elements for a successful project

The Maine Yankee segmentation project demonstrated that the entire segmentation process could be performed using cold cutting techniques.

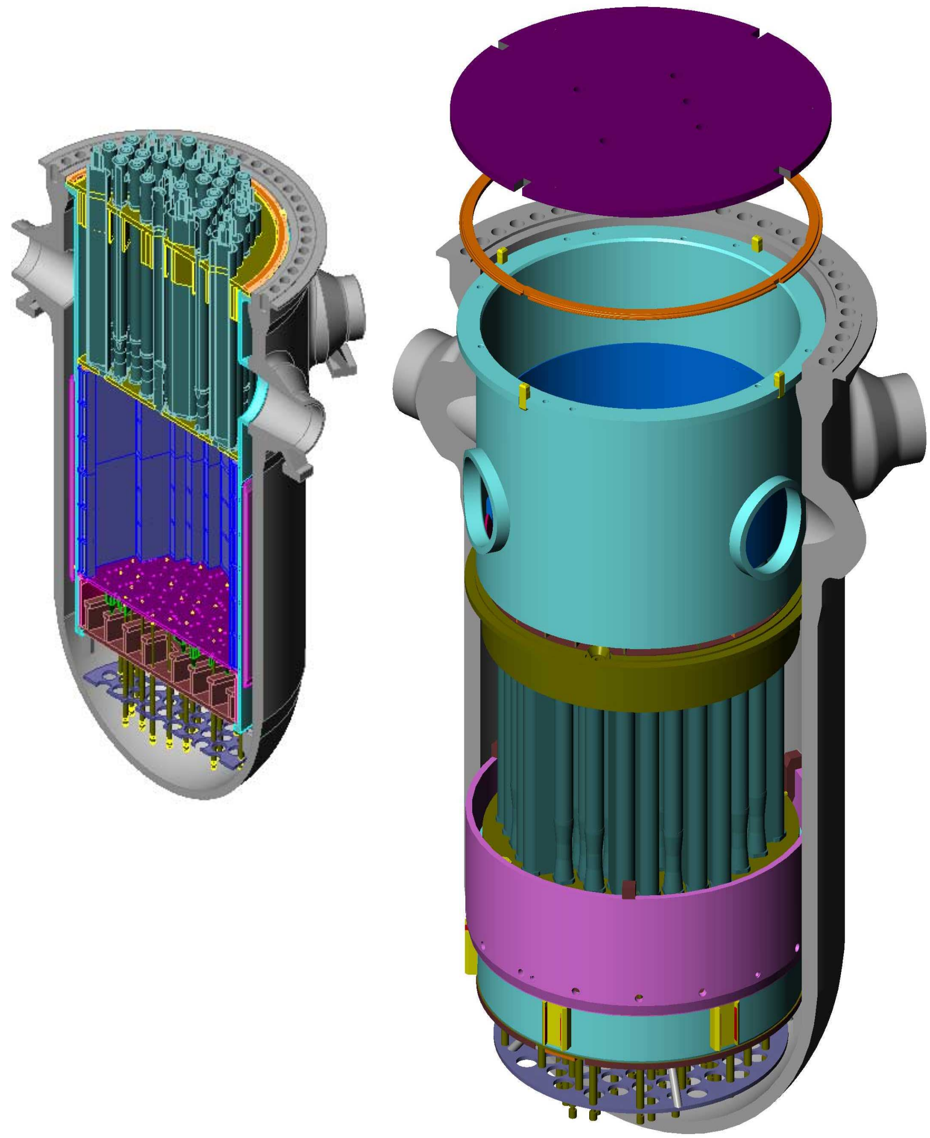

Figure 2-7
Maine Yankee RPV and Internals Prior to Segmentation

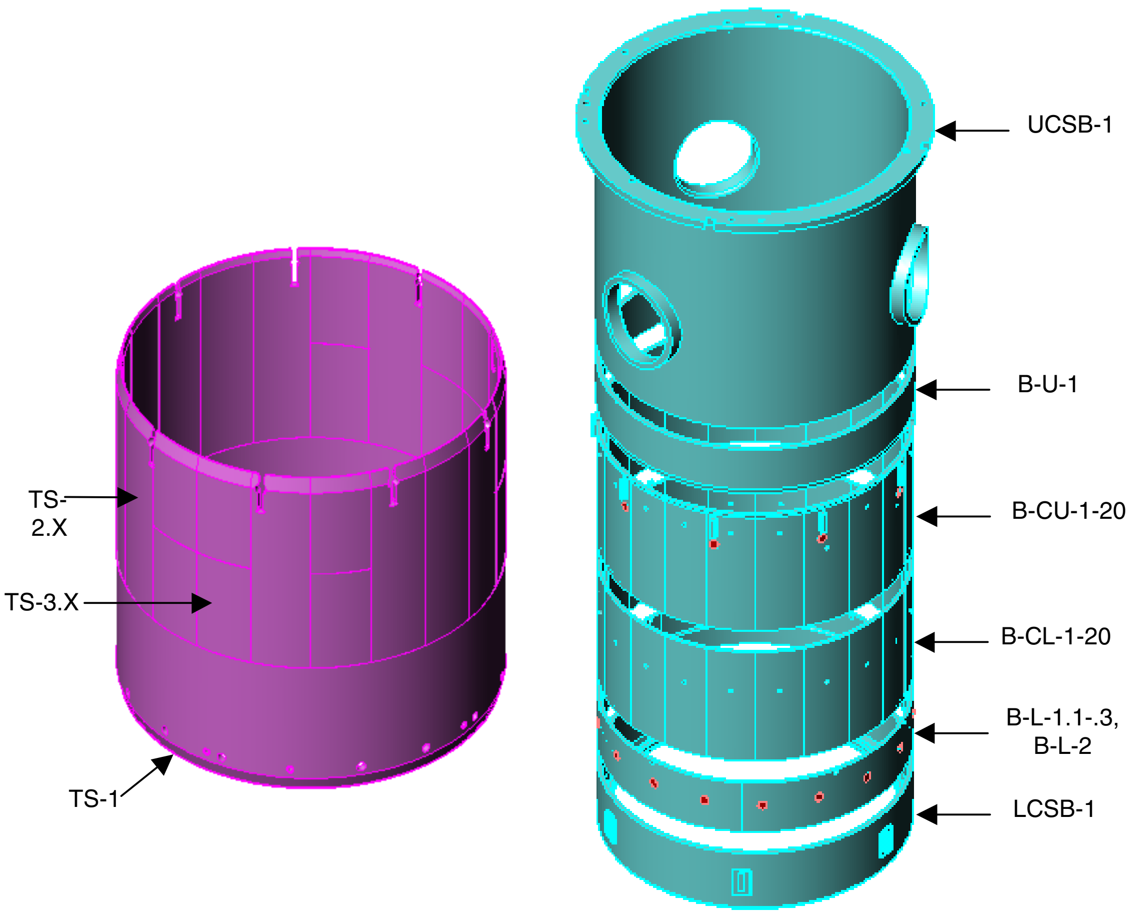

Figure 2-8
Maine Yankee Projected Cuts on the Thermal Shield and Core Support Barrel

Figure 2-9
Maine Yankee Custom Rigging Equipment

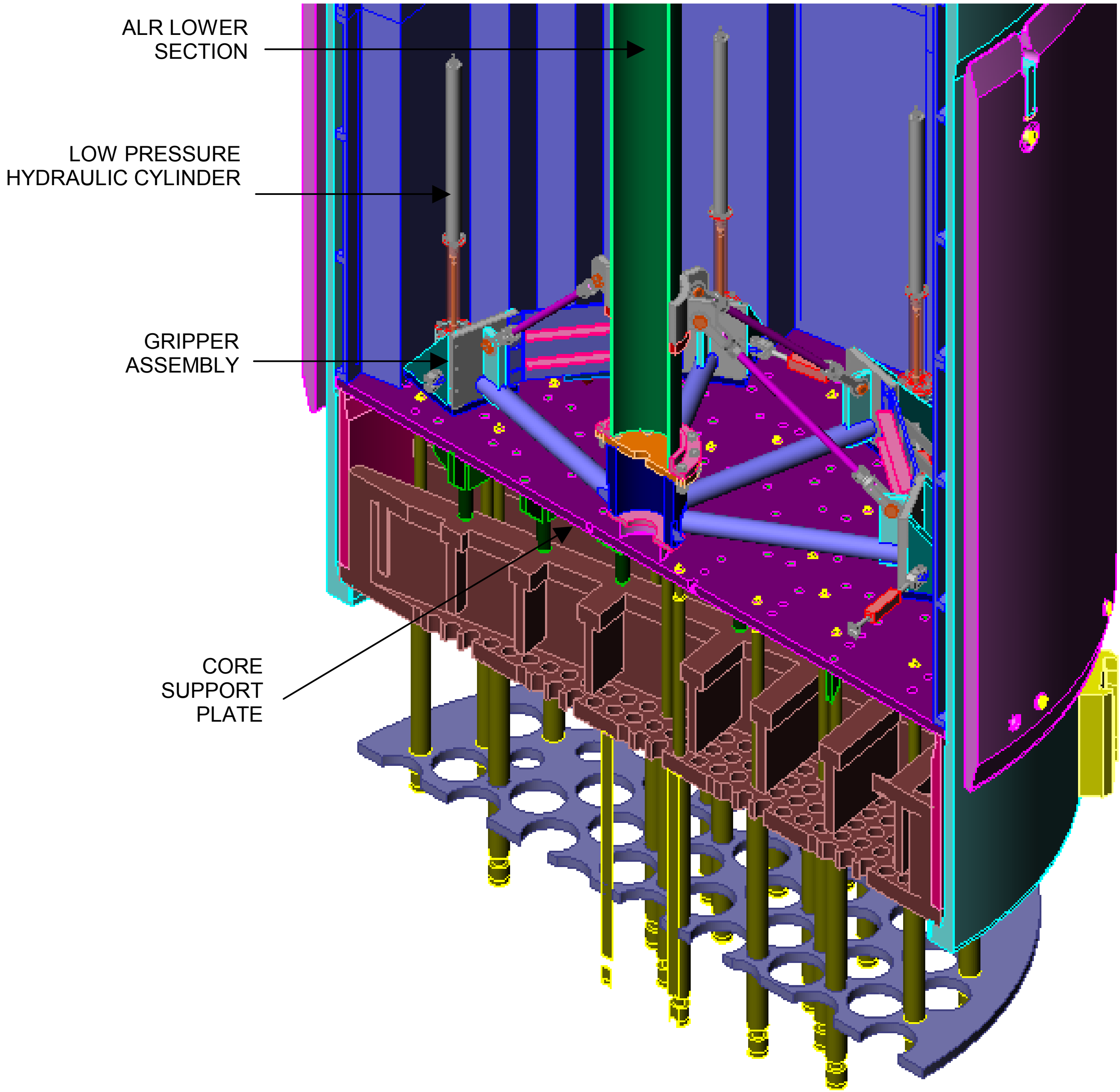

Figure 2-10
Maine Yankee Core Support Structure with Custom Rigging Equipment

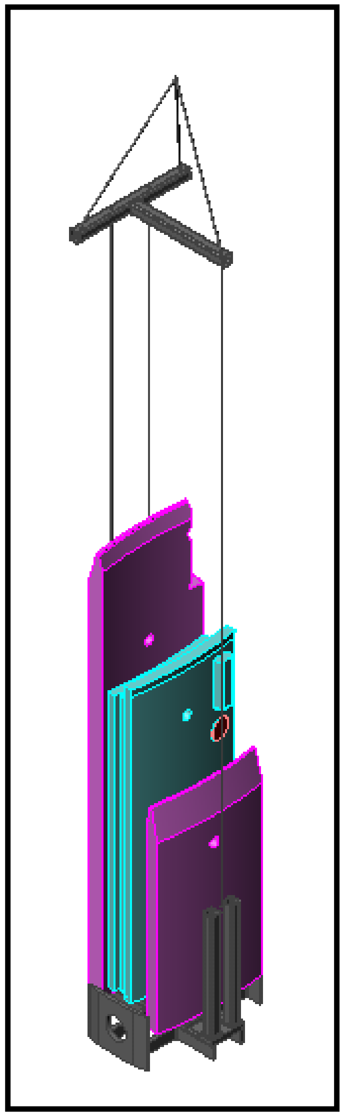

Figure 2-11
Maine Yankee Lifting of Larger Segmented Pieces

2.6 San Onofre-1

San Onofre-1 was a 436 MWe PWR owned by Southern California Edison Co. The unit began operation in 1968 and was shut down in November 1992 because of economic considerations due to safety related retrofit requirements. Decommissioning activities began in 1999 and mobilization for the RPV internals segmentation efforts began in February 2001. The objective of the RPV internals segmentation program is to segment and remove sufficient material from the RPV so that the vessel and some portion of the internals can be shipped as a single unit to Barnwell. Plans call for the segmentation and removal of approximately 31,400 pounds of activated metal with a radionuclide content of approximately 330,000 curies. (9) The projected exposure for the RPV internals segmentation is 73 person-rem and the projected cost is $20 million.

Prior to the RPV internals removal, the reactor hot and cold leg piping were cut and plugged to prevent any water leakage from the reactor. Water was added to the refueling cavity to the bottom of the closure head. The closure head was lifted and water allowed to flow into the reactor vessel to provide additional shielding from the vessel walls and the internals. The reactor head was removed and placed in the storage stand location where it will stay until it is ready to be packaged for disposal. The water level was raised to fill the refueling cavity and the internals removed from the reactor vessel and placed on a cutting table in the forty foot portion of the refueling cavity. The refueling cavity has two levels. The upper level is at a twenty-five foot depth, while the lower level is at a depth of forty feet. Figure 2-12 shows the filtration system and GTCC storage racks in the upper cavity level. Figure 2-13 shows the cutting enclosure support frame in the lower cavity level.

The RPV internals segmentation has been performed in accordance with the vendor segmentation plan approved by Southern California Edison. The plan describes the equipment to be used, the vessel disassembly sequence, the cutting methodology, component segment handling, and support systems necessary to complete the work. The selected vendor's workscope includes providing the necessary engineering, design, fabrication, inspection, testing, labor, supervision, materials, equipment, tools, supplies, services, and ancillary facilities required to segment the RPV internals. The vendor's workscope also includes placing the Greater Than Class C segmented material into Southern California Edison supplied waste containers. Prior to performing any segmentation work, a readiness review was performed for both Southern California Edison and PCI, the segmentation vendor. Table 2-5 shows the areas evaluated in the readiness review.

Table 2-5
Southern California Edison Segmentation Readiness Review

Southern California Edison	Segmentation Vendor
Laydown Space	Procedures
Utilities	Personnel
Cavity Integrity	Equipment
Crane Support	Testing
Personnel Support	Lessons Learned
GTCC Containers	ALARA
	Schedule

Extensive use of mockup training was also utilized prior to any segmentation. Figure 2-14 shows a core baffle mockup at the segmentation vendor's facility.

The majority of cutting of the RPV internals has been performed with abrasive water jet cutting. Metal disintegration machining (MDM) was utilized for some specialized cutting operations. Extensive use has been made of lessons learned from other utilities that have completed RPV internals segmentation activities. Enhancements to the procurement segmentation specification included an integrated equipment performance test and limits for the background dose increase and water activity during the cutting operations. Other enhancements included a limit on the maximum radwaste volume and criteria on cavity water restoration.

In order to keep personnel exposure as low as reasonably achievable (ALARA) a number of dose reduction activities were implemented. These included the use of lead shielding on personnel bridges, personnel water shields for the operators, and the use of surface skimmers for the cavity water. Other dose reduction efforts included the underwater changeout of the MDM electrodes, the use of a suspended gas collection hood, and the use of tooling with a polished or hard anodized finish. A low dose waiting area was also provided and is shown in Figure 2-15.

The cutting process was supported by a water filtration system and local capture devices to collect and filter the cutting residuals. Filtration enhancements as a result of lessons learned form Connecticut Yankee include increasing the flow rates through the cyclone separators, filters and ion exchanger in order to reduce the overall water processing time. The cyclone separator efficiency has also been improved. The underwater filtration system is shown in Figure 2-16. Operation improvements included pump vibration monitors and additional redundancy.

The majority of the cutting was performed in the forty foot deep portion of the reactor cavity and the cut zone was isolated, with positive enclosures, from the remainder of the pool. Secondary waste, garnet, and metal fines were packaged in approved High Integrity Containers to be shipped to Barnwell. The majority of the work was performed remotely from a control station located on the refueling floor. Occasional equipment or material handling required personnel to perform work on a shielded manipulator bridge located above the pool. Underwater and area cameras were utilized to monitor all of the work. Figure 2-17 shows an underwater camera and the abrasive water jet mounted on the mast used for controlling the cutting operation.

Cutting of GTCC components began in July 2001. Southern California Edison personnel elected to use larger GTCC storage containers than were used at Connecticut Yankee in order to reduce the number of cutting operations and increase the size of the segmented pieces. Table 2-6 shows a comparison of the SONGS and Connecticut Yankee segmentation activities.

Table 2-6
Comparison of Projected SONGS verses Connecticut Yankee Segmentation Scope

Segmentation Method	Item	SONGS	Connecticut Yankee
Abrasive Water Jet	Number of cuts	325	1,738
	Linear inches	10,821	23,251
	Cutting time (hours)	139	441
MDM	Number of Cuts	1,363	279
	Cutting time (hours)	110	66

The San Onofre GTCC storage containers are 16 inches square with lengths of either 6 ½ or 7 feet. The storage containers are designed to weigh less than a spent fuel assembly when fully loaded with GTCC material. This design was chosen to facilitate acceptance of the containers by DOE at some date in the future. It is expected that 22 GTCC containers will be needed to hold the segmented GTCC internals. The spent fuel transfer pool has been modified for use as an interim storage location for the 22 containers of GTCC waste. The 22 GTCC waste canisters cannot be stored in the San Onofre 1 spent fuel pool because of their dimensions. The GTCC waste will be temporarily stored in the spent fuel transfer pool until an Independent Spent Fuel Storage Installation (ISFSI) facility can be completed and the waste can be stored in the ISFSI. Eventually, plans call for shipping the GTCC waste along with the spent fuel to a licensed DOE waste facility.

Prior to the start of the GTCC segmentation the seals failed on both the recirculation pumps on the filtration skid. This required the skid to be removed from the refueling cavity pool. Additional time and resources were required to resolve the seal problem. A modification was made so that the pumps could be replaced without taking the filtration skid out of the pool. One lesson learned was to fully test the filtration skid prior to bringing it on site. The filtration skid should be designed so that all the active components can be replaced or repaired from the surface without requiring the filtration system to be removed from the pool. The system should also be designed to avoid crud traps that can become a high dose source. Since the avoidance of crud traps may not always be possible, the filtration system should be designed so that high pressure water wands or other devices can be used to dislodge any crud buildup.

Other lessons learned form the San Onofre 1 segmentation process included the following:

- The use of local collection hoods was important in capturing the cutting debris.
- The use of an improved cutting enclosure also helped to capture the cutting debris.
- An increase in the mast rigidity improved the cutting process by minimizing the drift of the cutting jet.
- A reduction in the high integrity container de-watering filter size was achievable and helped minimize radioactive debris from reentering the pool.
- The addition of a load cell to monitor High Integrity Container fill volume was important in maximizing the amount of material loaded into the container.
- The addition of a load cell to monitor the grit consumption of the abrasive water jet was beneficial in optimizing the grit usage.

The completion of the San Onofre segmentation project, including demobilization, is scheduled for February 2002.

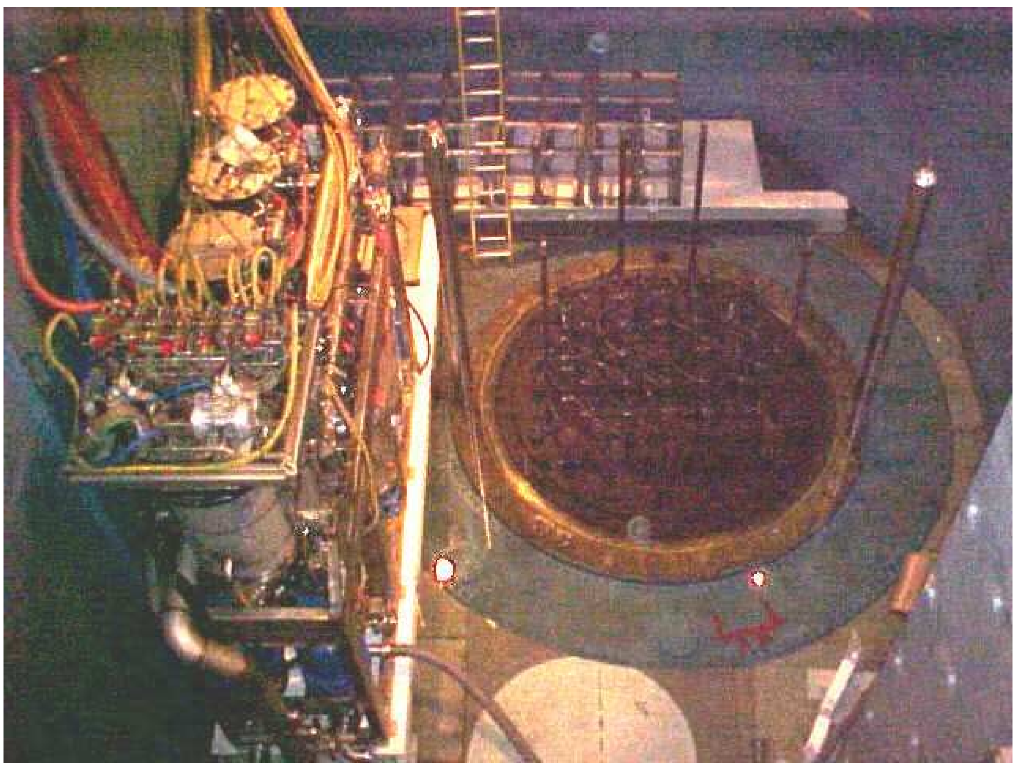

Figure 2-12
San Onofre 1 Upper Cavity Level

Figure 2-13
San Onofre 1 Lower Cavity Level

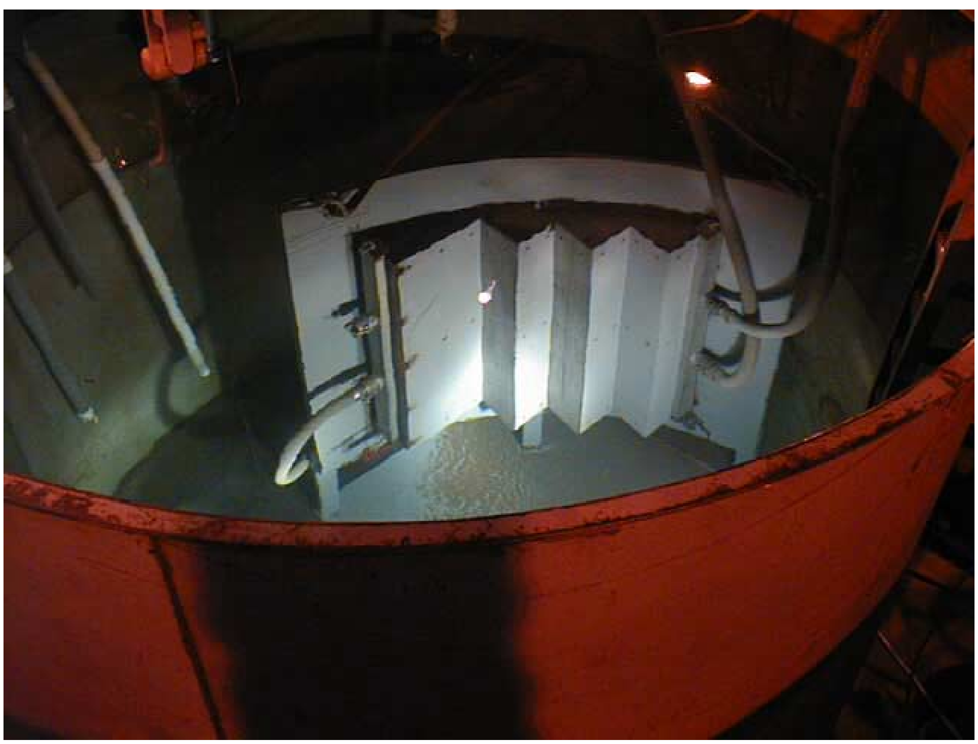

Figure 2-14
San Onofre 1 Core Baffle Mockup

Figure 2-15
San Onofre 1 Low Dose Waiting Area

Figure 2-16
San Onofre 1 Filtration System

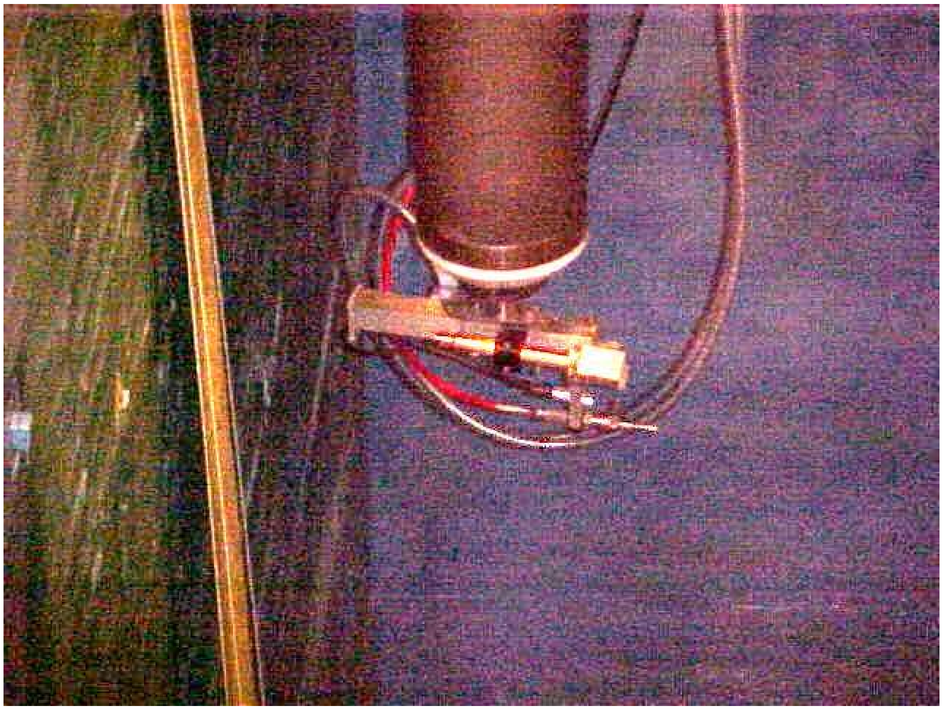

Figure 2-17
San Onofre 1 Mast Mounted Abrasive Water Jet and Camera

3
EUROPEAN EXPERIENCE

The European Commission (EC) has conducted research and development activities on the decommissioning of nuclear installations since 1979. (10) The decommissioning activities are carried out by public organizations and private companies in the member states under shared-cost contracts. There are five pilot decommissioning projects currently in progress. One project involves the decommissioning of the AT-1 facility in LA Hague, France which was a pilot facility built to reprocess spent fuel coming from the Rapsodie and Phenix fast breeder reactor units in France. The other four projects deal with the decommissioning of commercial nuclear plants. These plants include the BR-3 reactor in Belgium, the Gundremmingen KRB-A site in Germany, the Greifswald KRG site in Germany, and the Windscale Advanced Gas-cooled Reactor in England. Summaries of the activities at the four commercial reactor facilities are provided below.

3.1 BR-3 Reactor

The BR-3 reactor in Belgium was the first commercial PWR in Europe. The BR-3 began commercial operation in 1962 and was shut down in 1987 at the end of its license. The European Commission selected the BR-3 to be one of its pilot decommissioning projects in 1989 and the decommissioning activities began in 1991. (11) Prior to any dismantlement, a full system decontamination was performed on the unit using the Siemens Chemical Oxiding-Reducing Decontamination (CORD) process.

The RPV internals segmentation project was performed in several phases. The BR-3 reactor was first equipped with original Westinghouse internals. In 1964, after two cycles of operation, the internals, except for the thermal shield, were exchanged to perform an experiment with a new type of internals. The new internals experiment was named “Vulcain.” The Westinghouse internals were stored in a shielded chamber situated in a corner of the refueling pool. The Vulcain internals remained in the reactor for nine operating cycles until the final reactor shutdown. The RPV internals project covered the dismantling of both sets of internals. Phase 1 was the segmentation of the thermal shield, Phase 2 was the segmentation of the Vulcain internals, and Phase 2b was the segmentation of the Westinghouse internals.

Figure 3-1 shows a general view of the RPV with the Vulcain internals. Phase 1 of the segmentation project included segmentation of the thermal shield using three main cutting techniques. The three cutting techniques were the plasma arc, electric discharge machining (EDM) and mechanical cutting. The three cutting techniques allowed a direct cutting comparison on a single component. The thermal shield was a stainless steel cylinder approximately 3 inches thick, 8 feet high, and 4.6 feet in diameter. Cold testing of the three techniques were performed on non-radioactive mock-ups. This turned out to be very important and is recommended prior to performing any segmentation on radioactive components.

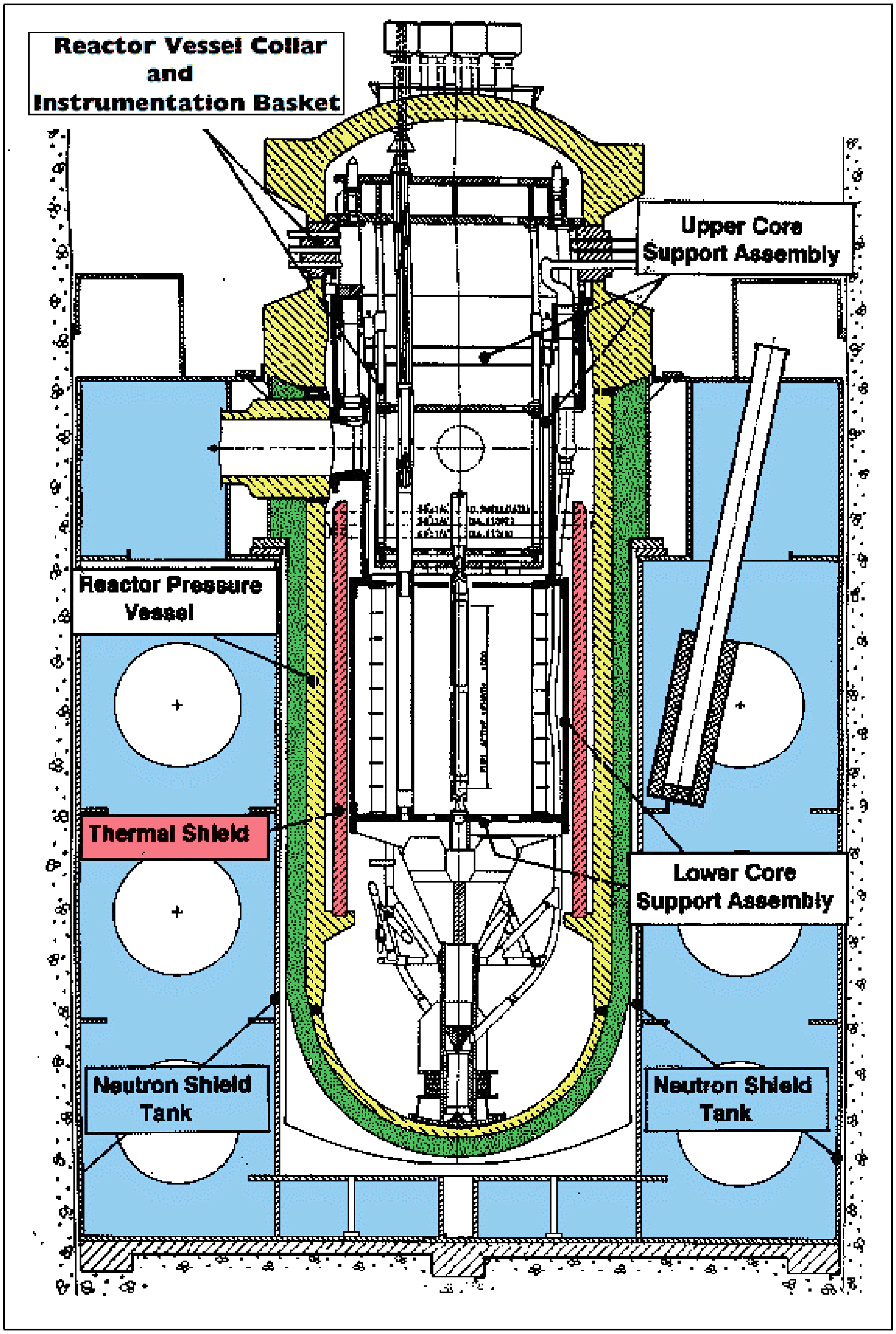

Figure 3-1
BR-3 RPV with Vulcain Internals

Table 3-1 provides a summary of the Phase 1 thermal shield segmentation.

Table 3-1
Summary of BR-3 Thermal Shield Segmentation

Cutting Method	Effective Cutting Speed (relative)	Dose Received (relative)	Secondary Waste Volume (relative)
EDM	1/4	~ 3	~ 5
Mechanical	1	1	1
Plasma Arc	1.6	~ 1	~ 5

The absolute cutting speed of the plasma arc method was much faster than mechanical or EDM cutting. However, the effective cutting speed of the plasma arc was only slightly faster than mechanical cutting. This was due to longer preparation time and longer debris cleanup time for the plasma arc system. The EDM cutting was the slowest and consequently resulted in the most dose being received. The mechanical cutting produced the lowest secondary waste volume and was equivalent to plasma cutting with respect to dose received.

The results indicated the mechanical cutting was the preferred method for segmenting the thermal shield. The advantages of the mechanical cutting included using a proven technique, reduced waste volume, no emission of smoke and gas, and comparable cutting times to the plasma arc method.

Due to the Phase 1 results it was decided to use primarily mechanical cutting techniques for segmenting the Vulcain and Westinghouse internals. Both a circular saw and a band saw were used. The circular saw was used to make long horizontal cuts. The band saw was used to make both vertical and horizontal cuts. Both cutting techniques were reliable and effective. The band saw produced less waste than the circular saw and was 25 percent faster. Therefore, the band saw became the preferred cutting method. However, both methods were required and were compatible.

During the RPV internals segmentation, several other cutting techniques were used for specific applications. Hydraulic shears were used for quick cuts on pieces with a relatively small thickness. A core drilling machine was used to drill holes approximately 2 inches in diameter to assist in cutting using the band saw. A reciprocating saw was used to cut tubes that penetrated an instrumentation collar on the internals. EDM cutting was used for precise cutting of difficult to access bolts. All of these methods demonstrated that specific applications may require specialized cutting methods.

The segmentation of the both the Vulcain and Westinghouse internals provided some unanticipated results. The Westinghouse internals, which were irradiated for only two cycles, had the same order of magnitude of activity as the Vulcain internals that were irradiated for nine cycles. The cooling down period for the Westinghouse internals (approximately 31 years) was not sufficient to provide any important advantages to segmenting internals that had cooled down for only a few years. The amount of effort and exposure received was similar in the segmentation of both sets of internals.

Plans are also in place to segment the reactor pressure vessel. An engineering analysis was performed comparing two different approaches. The first approach was an in-situ approach where the RPV would remain in place and cut into rings. The second approach was to remove the RPV and place it into the refueling pool where it would be segmented. The second approach was selected because it simplified the overall segmentation and allowed the use of the same dismantling tools that were used for the internals segmentation. The horizontal cuts have been made with a circular saw while the vertical cuts are being made with a band saw. The segmented RPV components will be loaded into special canisters for storage and burial.

The BR-3 lessons learned included the following:

- When plasma arc, mechanical, and EDM cutting were directly compared on the BR-3 thermal shield, mechanical cutting was the most effective and produced the lowest waste volume.
- Comparing mechanical cutting techniques, a band cutter was slightly more effective than a circular saw.
- The Westinghouse internals, which were irradiated for only two cycles, had the same order of magnitude of activity as the Vulcain internals that were irradiated for nine cycles.
- The cooling down period for the Westinghouse internals (approximately 31 years) was not sufficient to provide any important advantages to segmenting internals that had cooled down for only a few years.

3.2 Gundremmingen KRB-A

The KRB-A unit was a 237 MWe BWR near Gundremmingen, Germany. The unit went commercial in 1966 and was shut down in 1977. Decommissioning activities began in 1983. Much of the decommissioning activities have been in the balance of plant area. One innovative technique that has been used has been named the “ice-sawing technique”. The concept is to fill up a heat exchanger, such as the shut-down cooler, with water and to freeze the whole component by blowing cold air through the primary side. The concept is shown in Figure 3-2. After freezing, it is possible to cut through the entire component by using a suitable band saw. The advantages of this method include the following.

- Reduction of the local dose rate
- Fixing and supporting the heat exchanger tubes
- Minimizing the aerosol generation during segmentation
- Cooling the saw blade

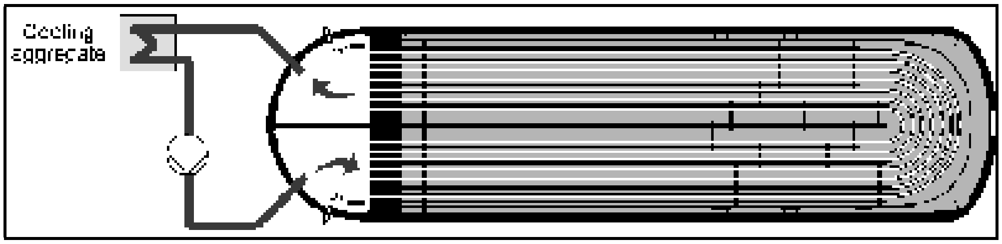

Figure 3-2
KRB-A Ice-Sawing Concept

Plans at KRB-A include segmenting the reactor vessel internals and then segmenting the entire reactor pressure vessel.

3.3 Greifswald KGR

The KGR site is located near Greifswald, Germany. The site contains eight pressurized water reactors of the Russian VVER design. The first unit went commercial in 1973 and the fourth unit went commercial in 1979. After German reunification, a decision was made to shut down the four operating units, stop operational testing on unit five, and halt construction on units six through eight. The units were shut down in 1990 and a decommissioning license was obtained in 1995. Decommissioning work on unit five began in 1996 and decommission activities on the other four units are scheduled from 2000 through 2005. The Greifswald KGR project is believed to be the world's largest decommissioning project.

A unique aspect of this project is the development of an on-site interim storage facility named Interim Storage North (ISN). Spent fuel has been removed from the reactors and the spent fuel pools and transported in dry casks to the ISN.

The reactor pressure vessels with internals are being removed intact and transported to the ISN. Plans are to allow the reactor pressure vessel and internals decay for several years prior to segmentation. The segmented pieces will then be repacked for storage at the ISN. The ISN will also be used for the interim storage of other radioactive material produced during the decommissioning and dismantling process. Final decommissioning activities at the site are not scheduled to be completed until 2012.

3.4 Windscale Advanced Gas-cooled Reactor

The Windscale Advanced Gas-cooled Reactor is located near Sellafield, England. The 100 MW thermal unit began commercial operation in 1963 and was shut down in 1981. The Advanced Gas cooled reactor used CO_2 as the cooling agent and the moderator is made of graphite bricks with channels that allow the insertion of uranium fuel elements. The reactor was incased in a steel-lined pre-stressed concrete pressure vessel several meters thick. Due to the unique design of the Advanced Gas-cooled Reactor, the decommissioning processes poses some problems not encountered with PWR's or BWR's.

The decommissioning activities performed to date have included the removal of 247 standpipes which penetrate the reactor pressure vessel. The majority of standpipes were removed using a plasma arc cutting device. The top dome was the upper hemispherical head of the reactor pressure vessel. The initial plan was to cut the dome into sections of approximately one square meter and remove these through a temporary door above the reactor pressure vessel. Due to the radiation exposure encountered it was decided to make a large circumferential cut in the dome and remove this section in one piece for further segmentation in a low exposure area. The circumferential cutting was performed with an industrial oxyacetylene torch. The torch was mounted on a remotely operated tracked vehicle. The removed top dome section was placed in a ventilated temporary containment and further segmented.

The lessons learned form the Winscale Decommissioning included the following:

- Use radiation dose as a primary criterion for selecting the dismantling and cutting methods.
- Remove large components and sub-assemblies form high radiation areas to areas of lower radiation for further segmenting.
- Segmentation and dismantlement testing on non-radioactive components should be performed prior to working on radioactive components.

The results at the Windscale Advanced Gas-cooled Reactor indicate that dose exposure should be the primary criterion for determining the most appropriate dismantling and cutting methods.

4
REACTOR PRESSURE VESSEL AND INTERNALS DISPOSAL – ANOTHER APPROACH

The disposal of the reactor pressure vessel and internals is simpler and easier if the reactor pressure vessel could be disposed of intact. Several utilities have been able to ship the reactor pressure vessel and internals to the Hanford burial site.

4.1 Shippingport Atomic Power Station

The Shippingport Atomic Power Station was the first U.S. large-scale, central station nuclear plant and began operation in 1957. Shippingport was a 72 MWe LWR and was shut down in 1982. The Department of Energy decided to promptly decommission the facility to demonstrate that the dismantling of a full scale plant was both practical and cost effective. An engineering evaluation was performed comparing segmenting the RPV and internals verses intact disposal. The evaluation estimated that an intact RPV disposal would reduce radiation exposure by 150 person-rem and reduce the project duration by approximately one year compared to the segmentation option.

The Shippingport reactor pressure vessel was approximately 10 feet in diameter, 33 feet long, and weighed approximately 370 tons. The estimated radionuclide content of the RPV and internals was 13, 319 curies. Modifications were made to the vessel, closure head, and neutron shield tank in order to create a single , homogenous structure that could be removed and shipped to the burial site. The reactor pressure vessel, containing the internals and neutron shield tank, was filled with concrete grout. The reactor pressure vessel package was licensed as an NRC 10 CFR 71 Type B equivalent package. The completed shipping package weighed approximately 900 tons and was shipped via barge and heavy hauler to the US Ecology low level radioactive disposal facility near Hanford, Washington.

4.2 Trojan

Trojan was a 1130 MWe, four-loop PWR, located in northwest Oregon on the Columbia River. Trojan is owned by Portland General Electric (PGE) and began operation in 1975. The unit was shut down in 1993 because of economic and operational considerations including the inevitable replacement of the steam generators. In 1995, limited dismantlement activities began including the Large Component Removal Project that disposed of the four steam generators and the pressurizer. These components were packaged as their own shipping containers, barged up the Columbia River, and buried at the Hanford low level radioactive waste disposal facility. Due to the success of this project, PGE also initiated and implemented a packaged approach for the disposal of the reactor vessel and internals. PGE packaged the reactor vessel and its internals as its own radioactive material shipping container, removed the package from containment, barged it up the Columbia River, and buried it at the same burial facility as the steam generators and pressurizer. The most challenging aspect of the project was obtaining the many state and federal approvals needed for this disposal option (12).

4.2.1 Decommissioning Plan

The Trojan Nuclear Plant Decommissioning Plan was submitted to the NRC and the State of Oregon in January 1995. The plan called for the separate removal of the reactor vessel and reactor vessel internals. The plan provided that the reactor vessel internals would be segmented in the flooded reactor cavity. Segmented portions that were classified as low level waste would be packaged and shipped to the Hanford low-level waste disposal facility. Segmented portions that were classified as Greater Than Class C waste were to be placed in canisters fabricated to standard fuel assembly size and initially stored in the spent fuel racks in the Trojan spent fuel pool. Options for storing the GTCC waste until a federal high level waste facility was available included the following:

1. Transferring the canisters to an on-site Independent Spent Fuel Storage Installation (ISFSI)

2. Obtaining a 10 CFR 30, "Rules of General Applicability to Domestic Licensing of Byproduct Material,"license concurrent with, or as part of, an ISFSI license

3. Obtaining a byproduct license from the State of Oregon

4. Retaining the Trojan Nuclear Plant license

The first and third options required rulemaking prior to implementation, the second option faced a challenge in that the NRC was concerned with the lack of specificity with 10 CFR 30, and the fourth option could be challenged since no power plant would remain at the site.

The 1995 Decommissioning Plan provided for the reactor vessel to be removed intact or sectioned. If removed intact, the vessel would serve as its own shipping container or possibly require certification as an exclusive use shipping container. The reactor vessel head would also be disposed of intact or sectioned. The successful experience with the disposal of the steam generators and pressurizer led PGE to seek approval for an innovative approach to the reactor vessel and internals disposal.

4.2.2 Regulatory Approvals

The Reactor Vessel and Internals Removal (RVAIR) Project was a complex project that required numerous precedent-setting regulatory approvals. The approvals were gained over a three year period. The following is a summary of the most important regulatory approvals obtained:

- **Nuclear Regulatory Commission**

  Certificate of Compliance for the reactor pressure vessel to be shipped as a Type B package (based on alternate transport conditions) in accordance with 10 CFR 71.12(c)(3).

- **US Department of Transportation**

  Exemption from DOT-E 12147 which then allowed for a one-time shipment of the reactor pressure vessel.

- **State of Oregon**

  Approval of the State of Oregon Energy Facility Siting Council for a change to the original Trojan Nuclear Plant Decommissioning Plan.

- **State of Washington**

  Approval of classification of the reactor pressure vessel and internals as Class C waste the could be buried in a low level radioactive waste disposal facility

The approval from the State of Washington was the most difficult to obtain. To classify the reactor vessel and internals as Class C waste, the dose pathways analysis had to demonstrate that the package met the exposure and stability requirements of 10 CFR 61, Subpart C, "Performance Objectives," and equivalent State of Washington regulations. PGE submitted this analysis to the State of Washington Department of Health and answered numerous questions by both the Department of Health and the NRC. Final approval was granted by the Department of Health in November 1998.

4.2.3 Project Scope

The Reactor Vessel and Internals Removal Project (RVAIR) included removing the reactor vessel and its internals intact and preparing the package for shipment. The reactor vessel was a cylindrical shell with an integral hemispherical lower head and a removable hemispherical upper head. The overall dimensions were approximately 42 feet in length and 17 feet in diameter. The vessel thickness (excluding the stainless steel cladding) varied from 5 3/8 inches at the lower head to 10 ½ inches at the nozzle ring. The reactor vessel was primarily made from SA-533 Grade B Class 1 carbon steel. The reactor vessel internals consisted of an upper internals assembly and a lower internals assembly. The internals were constructed of stainless steel.

The radionuclide inventory in the reactor vessel and internals consisted of both internal surface contamination activity and neutron activation activity. Accounting for the five years of radioactive decay since operation, the reactor vessel and internals were estimated to contain 155 curies of inner surface activity and 2,010,000 non-releasable curies of activated metal.

An opening had already been cut in the south face of the containment building for the removal of the steam generators and pressurizer. This opening was enlarged for removal of the reactor vessel. A large roll-up door was installed over the opening. After all the regulatory approvals were received, the reactor vessel was drained and filled with low-density cellular concrete. The piping and other components attached to the reactor vessel were cut. Closures were welded over all openings. Steel shielding was installed to reduce radiation levels within the required levels for transportation. The exterior of the vessel was decontaminated and coated as necessary to achieve the contamination limits specified in 10 CFR 71 and US Department of Transportation regulations.

Lift systems were constructed and tested inside and outside the containment building. The lift systems were used to load the reactor vessel to a transporter where it was moved to a barge for transport to the Hanford facility. At the barge slip in the State of Washington, the loading process was reversed. The transporter was moved off the barge and moved overland approximately 22 miles to the Hanford site. At the disposal site, the reactor pressure vessel was off-loaded into the disposal trench for final burial.

4.2.4 Project Advantages

The Reactor Vessel and Internals Removal Project had many advantages compared to separate reactor vessel removal and internals segmentation. Advantages included the following:

- **Less Waste Volume** - the RVAIR option resulted in 8,341 cubic feet of Class C waste compared to a projected volume of 18,320 cubic feet of low and GTCC waste for the segmentation option
- **Less Personnel Exposure** – the RVAIR option resulted in 67 person-rem for on-site occupational workers compared to a projected 133 person-rems for the segmentation option. Exposure for members of the general public and for the disposal facility workers were also less
- **Fewer Radioactive Shipments** – the RVAIR option involved only one radioactive shipment compared to an estimated 45 shipments with the segmentation option
- **Less Cost** – in 1996 dollars the RVAIR option was estimated to cost 23.8 million compared to an estimated 38.4 million for the segmentation option. The actual disposal cost was 4.2 million under budget and resulted in a savings of approximately 19 million dollars compared to the segmentation option.

In the end, the project was deemed both a technical and a financial success. The US Ecology facility is currently available only to the Northwest and Rocky Mountain compact states. Since 1996, regulations for disposal of large radioactive components has become more complicated. Unless changes are made to the current regulations or Barnwell relaxes its limit of 50,000 curies per shipment, the option to dispose of the reactor pressure vessel and internals in a single package will not be available to the commercial nuclear plant decommissioning projects.

Significant lessons learned from the Trojan experience include the following:

- In order to ensure schedule statuses are obtained on a routine and timely basis from contractors performing offsite work, additional details addressing this issue should be included in the contracts. Specifics such as schedule level of detail, schedule issue dates, milestone dates, and frequency of schedule updates should be negotiated up front with the contractor. If possible, the contractors should use the same scheduling software for their schedules as is used for the overall project schedule.
- Determining the amount of time it will take government regulators to approve new and innovative methods is a difficult task. The amount of schedule contingency needs to be

relatively large. Working schedules should be developed to target early completion of regulatory activities but contingency schedules should also developed to account for late completion.

- It is critical to involve outside agencies in the transportation planning to minimize delays during the actual shipping.
- The Trojan staff received a letter stating the transportation route to the burial site was satisfactory. However, no check for physical interferences was performed. When interferences were discovered, it was late in the project and the attention of upper management was required. A detailed check for physical interferences should be performed early in the project and checked again near the end of the project.

Figure 4-1
Trojan RPV on Ground Transporter

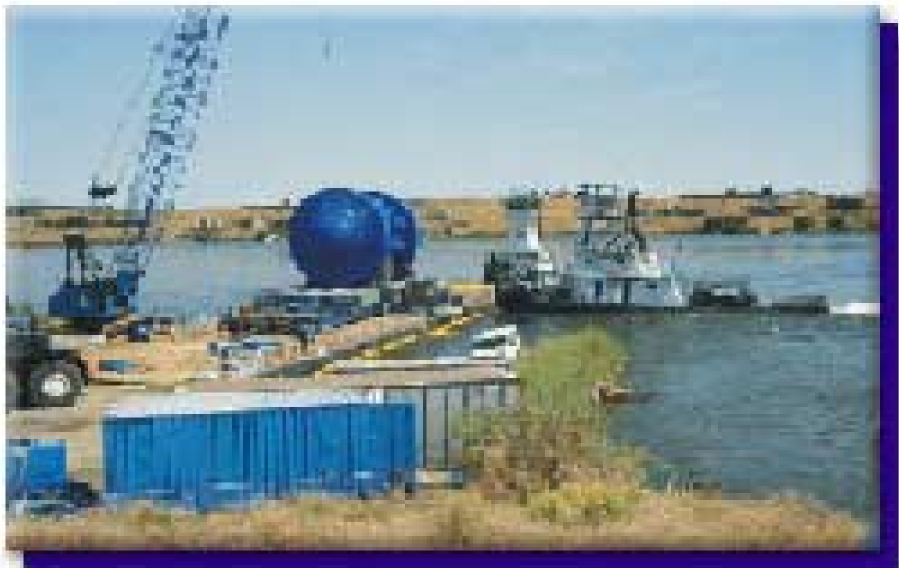

Figure 4-2
Trojan RPV at Barge Loading Dock

Figure 4-3
Trojan RPV on Barge

Figure 4-4
Trojan RPV Ready for Burial

5
SUMMARY AND RECOMMENDATIONS

Reactor pressure vessel internals segmentation is one of the most difficult and challenging tasks in decommissioning. The earlier segmentation projects used plasma arc cutting as the primary segmentation method. The disadvantages included the high amount of energy required, the amount of debris and off-gas generated, and maintaing water clarity during the cutting process.

The most recent RPV internals segmentation projects have used abrasive water jet cutting as the primary cutting method. The advantages include a reasonable cutting speed, less energy requirements than with plasma arc cutting, and avoidance of a waste gas collection system. The disadvantages include the difficulty in removal of the colloidal suspension created from the fragmentation of the garnet used in the abrasive water jet cutting.

Extensive predeployment planning, simulation, and testing are recommended prior to any on-site segmentation work. It is also recommended that a in a 3-dimensional CAD-CAM software package be used to model the reactor pressure vessel and internals. The segmentation process and the handling and packaging of the segmented pieces can be simulated prior to the work being performed. A computer simulation can help identify and mitigate any number of high risk factors.

There are a number of lessons learned that can contribute to a successful project. General lessons learned include minimizing the amount of cutting, maximizing the size of the remaining segmented pieces, and minimizing the amount of secondary waste generated. Recent segmentation projects have used canisters that are larger than fuel assembly size to store GTCC material. Maine Yankee used containers that were designed to hold 24 fuel assemblies. Each waste container holds two cylindrical canisters approximately 6 feet in diameter and 8 feet tall. Four waste containers with GTCC waste will be stored in the on-site Independent Spent Fuel Storage Installation (ISFSI).

One of the most difficult challenges in the entire segmentation process is maintaining water clarity and the removal of the debris created in the cutting process. Reliability and maintenance of the filtration system is a key to project success. At Maine Yankee the initial testing demonstrated that a simple filtration system quickly clogged. A specially designed and patented filtration system was needed for the actual water jet cutting operations. Two separate filtration systems were utilized. A Solid Waste Collection System (SWCA) was used in conjunction with a separate Cavity Water Treatment System (CWTS) in order to control debris cleanup and water clarity.

Other lessons learned from the segmentation projects include the following:

- At Shoreham a constructive dialog between the utility and the NRC Staff was established early in the project in order to discuss and resolve numerous questions and open issues. This allowed for early identification of problems and potential problem areas and often resulted in their early resolution.
- At the Yankee Nuclear Power Station it was determined that improvements in the debris collection system were needed and that starting the segmentation on the least irradiated components minimized the potential for cross contamination.
- The Maine Yankee segmentation project demonstrated that the entire segmentation process could be performed using cold cutting techniques. However maintaining water clarity and removal of debris with the filtration system were challenging elements.
- At San Onofre 1 it was determined that the complete filtration skid should be fully tested prior to bringing it on site. The filtration skid should be designed so that all the active components can be replaced or repaired from the surface without taking the filtration skid out of the cavity pool.
- In Europe the BR-3 segmentation project showed that for the segmentation of the thermal shield, specially designed circular and band saws had advantages over plasma arc cutting and electric discharge machining (EDM). In addition, the cooling down period for one set of internals (Westinghouse internals with approximately 31 years of cooling) was not sufficient to provide any important advantages to segmenting a second set of internals that had cooled down for only a few years.

The Shippingport and Trojan reactor pressure vessels and internals were disposed of without segmentation. The Shippingport disposal was a Department of Energy project and the Trojan RPV and RPV internals were analyzed such that the entire reactor vessel package was considered non-GTCC waste. Advantages of intact disposal include less waste volume, less personnel exposure, fewer radioactive shipments, and lower cost. Trojan personnel estimated they saved approximately $19 million and 66 person-rem compared to the segmentation option. Current regulations make this method of disposal highly unlikely to be approved. However, it is possible to segment the most radioactive internal components and ship the RPV and a portion of the segmented internals as a package to a low-level radioactive waste disposal facility such as Barnwell.

The segmented RPV internals that are highly radioactive are classified as GTCC material and placed in canisters for on site storage. Early segmentation projects used canisters with the approximate dimensions of nuclear fuel assemblies. Recent projects have used larger canisters and dry cask storage containers in order to minimize the segmentation process. All of the storage containers are temporarily stored in the spent fuel pool or an Independent Spent Fuel Storage Installation (ISFSI). The NRC has recently issued guidance that GTCC waste can be stored at a reactor site, including the cask storage pads of an Independent Spent Fuel Storage Installation (ISFSI), under a 10 CFR Part 50 license. The NRC staff is also preparing a proposed rule to modify 10 CFR 72 to allow storage of GTCC waste in an ISFSI under the authority of a site-specific 10 CFR Part 72 license. A final waste disposal solution will not be available until there is an approved DOE that accepts both GTCC radioactive material and spent nuclear fuel. Since this is an area where the regulations are changing, utilities need to stay actively involves in order to determine the best available options.

6
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