REACTOR PRESSURE VESSEL REMOVAL AT A BOILING WATER REACTOR WITH SPENT FUEL IN THE ADJACENT FUEL POOL

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ABSTRACT

A Reactor Pressure Vessel Removal Feasibility Study was prepared for use in the decommissioning planning for the Oyster Creek Nuclear Generating Station. The primary consideration of this study was to determine if the RPV could be safely removed from a boiling water reactor with spent fuel in the adjacent spent fuel storage pool. The scope of the study included:

- Developing alternates for prompt removal of the Reactor Pressure Vessel (RPV) intact (with or without internals), in sections (large pieces), and in segments (small pieces).
- Identifying applicable licensing requirements, heavy rigging equipment, cutting methods and tooling, building modifications, and engineering safety features for protection of the spent fuel pool and associated equipment.
- Providing schedules, comparative cost estimates, personnel radiation exposure estimates, and an occupational safety assessment for the feasible alternates.

The study determined that there were several feasible methods of safely removing the RPV with spent fuel in the adjacent spent fuel storage pool. The best method for removal was judged to be intact removal by lowering the RPV along a path through the bottom of the Drywell rather than lifting the RPV above the Drywell. This method was selected because its dose, cost and schedule duration provide the best combination of these parameters while eliminating the risk to the spent fuel pool by employing a single failure proof rigging system. Further, this alternate retains the option of leaving the lower internals inside the RPV, which substantially reduces the dose, cost and schedule duration relative to other methods requiring removal of the internals. Of the intact alternates, the lower Drywell method also provides the best opportunity for regulatory acceptance.

This paper provides a summary of the various considerations, inputs, characteristics, factors, and results from the study related to removing the RPV from the Reactor Building. This paper also provides the final conclusions of the study - that safe removal of the RPV can be accomplished from a BWR with spent fuel in the adjacent fuel pool in compliance with all NRC regulatory and license requirements.

INTRODUCTION

One of the first major tasks in decommissioning a boiling water reactor nuclear power plant is the removal of the reactor pressure vessel (RPV). Typically, the RPV is housed in a Drywell that is directly adjacent to the structure containing spent fuel in wet storage.

This paper presents the results of a study made for decommissioning of the Oyster Creek Nuclear Generating Station (Oyster Creek). Oyster Creek employs a General Electric BWR2 design with a Mark 1 containment. The plant layout is shown Figure 1. The primary consideration of the study was to determine if the RPV could be safely removed with spent fuel remaining in the spent fuel storage pool.

This paper provides information developed in the study in the following areas:

Removal Methods: Technical information associated with several removal methods and appropriate RPV internals removal processes.

ALARA Approach**:** A project execution approach considering ALARA principles including comparisons of dose estimates for the removal alternates.

Cost and Schedule Assessments: Comparison of the costs of the removal methods and their schedule durations considering engineering work as well as construction activities.

Conclusions and Recommendations: A summary of the findings of the study and recommendations regarding the best overall removal methods.

RPV REMOVAL METHODS

Many RPV removal schemes were identified during the course of the study. The most favorable methods are addressed in this paper. They are:

- Three methods for removing the RPV "**Intact**" (in one piece, without the RPV head and without cutting the vessel).
- Three methods for removing the RPV in "**Sections**" (cutting the RPV into a few large pieces).
- One method for removing the RPV in "**Segments**" (cutting the RPV into numerous small pieces).

It was assumed that the RPV would be one of the first major dismantlement activities such that it would occur while fuel was still in the spent fuel pool. Any plant structures or components that interfered with RPV removal were assumed to be removed as part of the RPV removal task. Any other dismantlement activities taking place at the same time as RPV removal were assumed not to interfere with the resources, space, or time required to accomplish the RPV removal.

RPV Intact Removal

Intact RPV removal requires separating all attached piping from the vessel, disconnecting RPV supports and removing some of the internals. Intact removal does not require cutting up the vessel itself. The three methods of intact RPV removal assessed were: (Alternate 1) removal through the Reactor Building roof, (Alternate 2) removal above the refueling floor and through the Reactor Building end wall, and (Alternate 3) removal through the Lower Drywell.

In all three of the intact removal methods, the RPV head is removed prior to removal of the rest of the vessel. The RPV head is removed first for the following reasons:

- The head can be readily removed by unbolting it from the vessel
- The weight of the intact vessel can be substantially reduced, reducing the size and cost of the heavy lift equipment
- The head can be segmented and disposed of while other removal tasks are being set-up

The study started by determining the direction in which the vessel could be removed. This depends largely on access to the building and the relationship of the removal path to the spent fuel pool, located north of the Drywell at Oyster Creek; see Figure 2 for plant layout. The possibility of adverse effects on the spent fuel due to a postulated load drop during the removal process should be minimized. The vessel should not be moved directly over the spent fuel. Removal through the west side of the Reactor Building was not a good alternate because access was blocked by the Turbine Building. Even if the Turbine Building were removed, support for the RPV removal crane would have to be built up from the Turbine

Building basement. The eastern side of the Reactor Building would be a difficult removal direction because the off gas stack, auxiliary boiler building and the old radwaste building limited access.

The optimum removal direction is toward the (southern) end of the Reactor Building that is located away from the spent fuel pool and has clear outside access. A large crane, gantry system or other equipment could readily be set up without requiring the dismantlement of other structures.

In order to remove the RPV, it must be detached from all piping. Nozzles and control rod drive piping would be cut and plugged to minimize radiation exposure for the craft and complement the shielding required for off-site transportation and disposal. To provide clearance inside the bioshield and by the refueling bellows, the nozzles would be cut as close to the vessel as possible. Some of the bioshield wall pipe penetration openings are not large enough to allow making nozzle cuts from the outside of the nozzles. Rather than removing part of the bioshield wall and losing its shielding, access to the nozzles would be provided by removing a spool piece from the pipe and then making a final cut from inside the nozzle.

The RPV would also have to be detached from its structural supports. The RPV skirt bolts in the RPV pedestal would either be removed or cut and the snubbers which connect the RPV to the top of the bioshield wall would be removed. For the methods where the vessel is removed through the top of the Reactor Building, portions of the seal plate and the reactor cavity refueling bellows would be removed to provide clearance. The Drywell head would be removed in normal fashion using the Reactor Building bridge crane and would be placed on the refueling floor.

The RPV head and internals could be removed to reduce the lift weight and, in some cases, the vessel's overall dimensions. This facilitates the rigging design by increasing clearances and decreasing the lifting device's required capacity. The individual component weights are shown in Table I.

Table I -Summary of Weights

Component	Weight	Weight to be Picked in a Single Lift
RPV With Internals and Head	790 tons	-
RPV Without Internals or Head	577 tons	577 tons
Lower Internals (core shroud, control rod guide tubes, lower core plate, and top guide assembly)	64 tons	64 tons
Steel Cover Plates , Lifting lugs and Rigging Devices	~ 209 tons	~ 209 tons
Total		~ 850 tons

After placing the RPV head on the refueling deck, it would be wiped down, cut up, and coated with a contamination fixative as required for off-site shipment and disposal.

The RPV upper internals (steam dryer and separator) should be removed and disposed of prior to RPV removal. This is recommended for several reasons:

- The upper internals must be removed to provide access to the lower internals
- The upper internals project above the RPV top flange; a more costly top-hat style cover would have to be fabricated in lieu of a flat plate cover

- The upper internals could be segmented and disposed of separately at a lower cost as a Class A waste shipment
- The equipment pool is not large enough to allow storing the upper internals and all of the lower internals for reinsertion into the RPV at a later time

The upper internals could be cut under water in the adjacent equipment pool to minimize the possibility of airborne contamination.

When the reactor is drained, sludge will remain in the bottom of the RPV. The sludge would be pumped out of the RPV and low density cellular concrete (LDCC) would be added to fill the CRD tube stubs left in the bottom of the vessel.

A cover plate equipped with lifting lugs would be bolted and/or welded to the top of the vessel for shielding and for rigging purposes. Another lifting device would also be attached to the bottom of the vessel for tailing and down-ending.

Since the RPV is enveloped in blanket insulation, most of the insulation could be removed while the vessel was still within the bioshield wall. The remainder would be removed during extraction of the vessel.

A cover would be placed over the spent fuel pool during RPV removal activities. The cover would act as a foreign materials exclusion (FME) barrier preventing small tools and debris from falling into the pool. An evaluation of the spent fuel pool cooling system would be required to determine whether the loss of convective cooling, resulting from installation of the cover, required additional cooling capacity.

Alternate 1: Removal Through The Roof

To remove the RPV though the roof, a heavy lift crane would be erected on the side of the Reactor Building. The crane must be able to lift approximately 850 tons, as determined above. See Figure 2 for details of a typical heavy lift crane layout.

The RPV would not be lifted directly over the spent fuel pool, but would be lifted straight up, above the level of the Reactor Building roof. Even so, the consequences of a load drop adjacent to the spent fuel pool must be considered. To address NUREG 0554 requirements for single-failure-proof systems, load testing could be performed to establish the crane's safe lift capacity and the reeving from the boom tip to the lifted load could be doubled for redundancy. However, the possibility of the crane overturning in a seismic event must also be taken into account when addressing the issue of single-failure-proof systems. It is unlikely that any heavy lift crane could withstand a seismic event with a 850-ton load on its hook; thus it is impractical to make the crane single failure proof.

A section of the roof would have to be removed to allow for the removal of the RPV. Bracing would be added to compensate for the removed roof beams. The additional bracing would be designed to maintain the seismic integrity of the Reactor Building superstructure. The heavy lift crane's hook would be lowered through the Reactor Building roof opening and connected to the RPV lift rig. The vessel would be lifted vertically through the bioshield wall.

To support off-site transportation, the RPV may need to be shielded with steel around the core barrel region of the RPV. If the shielding plate were added prior to or during the RPV lifting process, a large load would be added to the vessel weight, substantially increasing the size and cost of a heavy lift crane. The shielding should not be added until the vessel is outside, adjacent to the Reactor Building where the crane's lift radius would be much smaller and lift capacity would be much larger. Local shielding around nozzles and other specific components could be accommodated in the interest of reducing personnel exposure during the lifting process.

The crane would lift up the vessel through the opening in the roof, carry it over to the south side of the Reactor Building and lower it to the ground. The down-ending rig, attached to the RPV skirt, would be used to connect the RPV to a down-ending stand situated on the ground adjacent to the crane. The RPV would be supported temporarily on cribbing in a horizontal position while the crane was disconnected from the RPV top flange lift rig. The crane would then connect to a lift beam which would raise the RPV horizontally and place it onto a transport trailer for off-site shipment.

Alternate 2: Removal Through The End Wall

The second alternate is to remove the RPV using a gantry system running under the roof trusses. An opening would be made in the end wall of the Reactor Building to allow for vessel and rigging clearance. This opening would be approximately 30 ft. wide. It would extend from the refueling floor to a location just below the bottom of the Reactor Building roof trusses. Some steel bracing members would also have to be removed. Additional bracing would be added to support and stabilize the wall in the area adjacent to the opening. The replacement bracing would be designed to maintain the seismic integrity of the Reactor Building superstructure.

In order to support the outside tower portion of the gantry system, a foundation would be constructed in the yard adjacent to the Reactor Building. A hydraulic crane would be used to erect the gantry and outside tower structure. Inside the Reactor Building, the gantry would be supported on columns. The runway beams and columns would be braced in both the north-south and east-west directions. To address NUREG 0554 requirements for single-failure-proof systems, the gantry's reeving could be doubled for redundancy. However, precluding the gantry from losing the 850-ton RPV in a seismic event would require erection of a massive, expensive gantry support structure adjacent to the spent fuel pool. Thus, it is deemed impractical to make the gantry single failure proof. An analysis would be required to address an inadvertent RPV load drop.

Two parallel lift devices, such as strand jacks or chain hoists, would be used to lift the RPV. The lift system would consist of a main lift rig connected to the RPV flange and a tail lift rig consisting of a lug and a supporting member bolted to the RPV skirt. The tail lift rig is required to pull the vessel into a horizontal position. The main and tail trolleys would then transport the vessel southward.

Once outside the Reactor Building, the RPV would be lowered onto saddles positioned on the transport trailer. See Figure No. 3 for details of the removal method and rigging.

Alternate 3: Removal Through the Lower Drywell

The third intact removal method is to take the RPV out through the lower Drywell. The advantage of this approach is that the vessel would not be raised above the level of the pool, essentially eliminating the risk of damaging the spent fuel pool due to a potential RPV load drop accident. If the RPV fell, it would impact the bottom of the Reactor Building, but would not directly impact the spent fuel pool.

The shock wave imparted to the building from an RPV fall can be expected to be less severe than a seismic event, thus posing a risk to the integrity of the spent fuel pool structure that could be mitigated through analysis. More significant from a licensing perspective is that a single failure proof means of intact RPV removal could be used with this alternate.

The vessel would be taken out of the Reactor Building in a direction away from the spent fuel pool as in the first two intact alternates. An opening would be made between just above ground level in the Reactor Building end wall. Temporary bracing would be erected to support the loads from above the opening. The temporary bracing would be designed to maintain the seismic integrity of the Reactor Building without significantly affecting the dynamic response of the structure. By maintaining the current dynamic response properties, the spent fuel pool and spent fuel rack design bases would be unaffected.

The RPV would be removed using a runway system constructed at grade level running from the southern end of the Reactor Building into the center of the Drywell. The runway would be erected approximately at grade level for easy cribbing of the runway.

Portions of the Drywell, bioshield and RPV pedestal walls would also have to be removed. Approximately half of the bioshield and RPV pedestal walls would be removed to allow clearance to lower, down-end, and remove the RPV. The remaining portion of the bioshield wall would be supported by the remaining portion of the RPV pedestal wall. The platforms inside the Drywell are supported by beams spanning radially out from the bioshield wall to the Drywell wall. In order to demolish half of the bioshield wall, some of the platforms would be removed.

Temporary support beams and strand jacks would be installed over the reactor cavity. After attaching the lift rig to the RPV top flange, the RPV would be lifted vertically about 1 foot and the jacks would be blocked. In this manner, the vessel would no longer be supported by the hydraulic lifting device. A second set of lift cables could be strung from the RPV to the temporary support beams, providing a lift system that would meet the intent of NUREG 0554 single-failure-proof lift systems. At this point, a portion of the RPV pedestal would be removed to allow down-ending of the vessel. The runway would then be erected under the vessel. As much as possible of the pedestal and runway work should be completed prior to lifting the vessel to minimize work performed under the vessel while it is suspended from the strand jacks.

A down-ending device, such as a pivoting tailing system, would be connected to the RPV skirt. to tilt the vessel until it was in a horizontal position. A saddle with rollers would be provided on the runway to support the upper portion of the vessel. The towing winch system would then pull the RPV out of the Reactor Building into the yard. The RPV could be lifted by an outside gantry onto a transport trailer. See Figure No. 4 for details of the removal method and rigging.

RPV Sectional Removal

For RPV sectional removal, three methods are discussed below: the vessel could be partially sectioned creating a package that would be removed by one of the heavy lift devices identified for Intact removal, or by sectioning the vessel into smaller pieces that could be removed by the existing Reactor Building crane.

Alternate 4 presents a way to section part of the RPV and uses the rest of the vessel as a shipping container. The Alternates 5 and 6 section the RPV into larger pieces. Size and weight limitations are imposed on the sections. The larger sections could be shipped as their own containers or packaged into large shipping containers.

Many of the same preparations made for the intact removal would also have to be made for the sectional removal. These include removal of the RPV upper and lower internals, cutting the RPV nozzles, removing the RPV support connections, and moving the Drywell and RPV heads to their storage locations on the Reactor Building refueling floor. Implementation details for the sectional methods are in the following sections.

Alternate 4: Upper RPV Sections Packaged into the Lower RPV

The upper portion of the RPV, the approximately 22 ft. long section which begins about 3 ft. above the core guide plate, would be segmented and placed inside the lower portion of the RPV while inside the Reactor Building, as shown in Figure No. 5.

The lower RPV could then act as its own shipping container or be packaged into a separate shielded shipping container. The upper pieces would rest on an LDCC or steel base approximately 10 ft. up from the bottom of the vessel. The upper pieces would also be braced laterally. The bracing should have an open design that would allow filling the RPV with LDCC prior to burial. A cover plate would be attached to the top of the shortened RPV.

Any of the three intact methods could be used to remove the sectioned vessel from the Reactor Building. The same issues apply with respect to lifting device load capacities, rigging equipment, load drop evaluations, and removal paths. Clearance requirements, however, are somewhat less stringent due to the reduced length of the sectioned RPV.

Alternate 5: Horizontal Ring Sections

In this method, the RPV shell would be cut into five horizontal rings, as shown Figure No. 6. Similar to the other methods, the RPV head and upper internals would be removed. The lower internals and lower head would also be removed, segmented, and shipped separately from the RPV. The upper, less contaminated portion of the vessel, would be shipped to a waste reprocessor. The lower, core area of the vessel would be shipped to a burial facility.

All of the sections would be removed through the equipment hatch using the existing Reactor Building crane. Once lowered through the equipment hatch, each piece would be placed on a saddle mounted on a rolling cart. Circular plates would be welded to each end of each ring, allowing each ring to be its own shipping container. The cart would transport the rings through the railroad airlock to an offsite transport vehicle.

Alternate 6: Short Vertical Sections

This method requires that the RPV be cut into two bands each with six short vertical sections, as shown Figure No. 7. Similar to the other methods, the RPV head and the upper internals would be removed. The lower internals would also be removed, segmented, and shipped separately from the RPV. The upper band strips would be placed in containers and shipped to a waste reproccessor. The lower band strips would be placed in shielded containers and shipped to an appropriate burial site. The lower head would be segmented, packaged, and also shipped to a waste reproccessor.

All of the pieces would be light enough and small enough that the Reactor Building crane could lift the pieces and remove them through the existing equipment hatch.

Segmented Removal

Alternate 7: Segmented

The segmented RPV removal alternate is defined by the physical dimensions of existing licensed shipping containers, thereby eliminating the need for unique regulatory approvals or engineering design. Because segmentation requires cutting the RPV into many small pieces, special cranes, building dismantlements or interference removal would not be required. These activities would be replaced with extensive cutting operations to reduce the RPV to small pieces. As shown in Figure No. 8, the top flange would be removed and segmented, the upper RPV shell would be cut into nine vertical strips, the core region would be cut into numerous small pieces, a 3 ft. ring above the lower head would be removed and segmented, and the lower head would be cut into eight sectors.

The core region pieces would be cut to fit inside shielded shipping casks for burial at an appropriate disposal site. The remainder of the vessel would be shipped to a waste reprocessor. Many of the same preparations made for the intact removal would have to be made for the segmented removal. These include cutting the RPV nozzles, removing the RPV support connections, and moving the Drywell and RPV heads to their storage stands on the Reactor Building refueling floor. These activities would proceed in the same manner as described in for Intact removal.

All of the pieces, including the shielded shipping casks, could be lifted by the existing Reactor Building crane. The pieces/casks would be lowered through the equipment hatch and staged in the Reactor Building railroad airlock. The casks could be transported off-site by road or rail.

Special RPV Load Handling Considerations

Load Drop Analyses

Evaluation of potential load drops during removal of the RPV are sub-divided into three categories:

1. Direct impact on the fuel pool.
2. Impact away from the pool, with much dynamic excitation of the fuel pool and associated mechanical and electrical systems resulting in the potential for significant loss of structural integrity.
3. Impact away from the pool, with nominal dynamic excitation of fuel pool and its associated mechanical and electrical systems resulting in minimal loss of structural integrity.

When planning the RPV removal sequence, the following results are anticipated and should be considered: Category (1) will not produce acceptable results, Category (2) may produce acceptable results, and Category (3) will produce acceptable results.

The drop of an intact RPV onto the refueling floor will produce significant dynamic excitation of the spent fuel pool and associated systems and require a detailed evaluation of these components. The removal alternate that requires lifting the vessel through the roof would result in a load drop scenario that suggests significant structural damage. Removal through the end wall using a gantry system would have less impact on the building, but would likely still produce significant excitation of the spent fuel pool.

A lower Drywell removal alternate minimizes the detrimental effects of potential load drops due to the small lift height required by this method. Load drop analyses could be entirely eliminated for the lower Drywell removal method if a single failure proof lift system were employed. Even without a single failure proof system, the drop height is readily controlled, and the point of impact is well removed from the spent fuel pool and associated systems that must be protected.

Dynamic excitation of the fuel pool island including associated mechanical and electrical equipment must be evaluated for all load drop scenarios. It is expected that the existing seismic qualification of the fuel racks in the pool can be shown to accommodate any vibratory response due to load drop. Similarly, mechanical and electrical equipment required for the spent fuel pool island should be seismically rugged. Shake table testing or qualification by analysis, typically performed for seismic category one equipment, may prove to be acceptable for excitation caused by load drop.

Building Seismic Analysis

Removal of a significant portion of the Reactor Building walls/columns and the Drywell bioshield/structure, as well as removal of the RPV mass (weight) could affect the seismic response of those structures. An analysis of the proposed dismantlement plan would be required to show that the structures and the remaining safety related systems (e.g., the spent fuel racks) were not adversely affected. Measures such as adding structural bracing may be required to mitigate the effects of the dismantlement.

RPV Internals Removal

Portions of the RPV internals will need to be removed from the vessel, segmented, and packed into shipping containers prior to shipping the RPV off-site. Removal of the reactor internals requires special cutting techniques, extensive planning and controlled dismantlement work. Thus, it is generally desirable to leave as many of the internals in the RPV as possible. This has the advantage of minimizing deployment of custom made cutting equipment and employing often tedious cutting operations. Defining which internals should be removed depends on which RPV removal method is selected.

Upper Internals Removal

The RPV upper internals, the steam dryer and moisture separator can be segmented in the equipment pool. An auxiliary bridge can be installed over the equipment pool and stop-logs or a barrier curtain wall should be installed to isolate the equipment pool from the reactor cavity area. The cutting apparatus is mounted to a manipulator attached to and controlled from the bridge. High quality lighting and vision systems mounted to pan and tilt units will be required to support all underwater activities. Water filtration will also be required. A cutting stand or table is required for segmenting large parts. Debris collection and contamination barriers can be incorporated into the cutting table design. Specialty clamping and rigging devices will be used to support and maneuver the cut pieces. A HEPA system connected to a floating hood may be used to collect off gases and filter any airborne contamination.

Lower Internals Removal

Boiling water reactor core area (lower) internals can be difficult to segment. Most of the pieces that make up this region are welded into place and to each other. Plasma arc cutting works extremely well in separating the pieces from the vessel and each other, but disturbs the surface contamination built up on the components. Abrasive water jet, spark erosion or mechanical cutting processes can be relatively slow but require less water filtration. A combination of all three types of cutting will likely be required, applying each process where it would be the most beneficial.

The distribution of surface contaminants combined with the Greater Than Class C (GTCC) material dispersed into the cavity from the kerf makes water filtration expensive. Debris barriers will be required to keep the spread of contamination to a minimum. Either large volume, deep bed filtration systems or large numbers of mechanical filters will be required depending on the cutting system. Care must be exercised to prevent the filtering media from becoming GTCC. A chemical decontamination of the RPV interior prior to segmentation work should be considered.

Internals Cutting Plans

A detailed reactor internal segmentation plan will be required upon selection of the RPV removal alternate and determination of the dimensional constraints and availability of shipping containers. The following subjects should be addressed when preparing a detailed plan for internals removal:

- Activity level of each component
- Size of shipping/storage container based on activity level
- Secondary waste generation and disposal
- Control of contamination and water clarity
- Control of radiation exposure
- Cutting method
- Piece handling, staging and placement in containers
- Optimization of waste container packaging

Since all RPV removal methods call for the removal of the RPV head, the steam dryer would also have to be removed. This is necessary because, once the head is removed, the steam dryer protrudes above the

RPV flange. It would be costly to fabricate a "top-hat" style cover to accommodate the steam dryer protrusion rather than use a flat plate cover.

The following sections of this study describe plans for segmentation of the various reactor internal components. The internals are grouped into two categories: those that can be shipped as low level radwaste (LLRW) and those that exceed Class C activation levels and must be handled as GTCC waste.

LLRW Internals Less Than GTCC

- Core Shroud: This component is expected to have very high activity levels. While most of the core shroud should be LLRW material, some pieces may exceed Class C limits.
- In Core Guide Tubes and Tie Rods: These components are expected to have high activity levels.
- Steam Separator and Steam Dryer Assemblies and Core Support Cone: These assemblies are expected to have moderate activity levels.
- Flow Baffle: This assembly is expected to have low activity levels. It may be possible to ship the flow baffle intact without segmentation.

LLRW Internals GTCC

The segmentation requirements for the GTCC internals are significant because these components must be cut into pieces that fit into fuel assembly sized shipping cans. These cans are typically six inches square.

- Top Guide: This cylindrical metal grid plate with reinforcing plates and skirt would require Skirt removal, Reinforcing Plate removal, Guide Plate segmenting, and a series of cuts to separate the Reinforcing Plates from the guide plate.
- Core Support Plate: This cylindrical plate would be cut to the same cut width requirements as given for the Guide Plate.
- Control Rod Guide Tubes: Portions of these units will not exceed Class C limits and can be disposed of as LLRW. Each of the 137 tubes would be surveyed to determine which portions could be disposed of as non-GTCC and as GTCC.

RPV Cladding Removal

The inside diameter of the Reactor Pressure Vessel is covered with a stainless steel material to prevent corrosion. By removing the cladding, the activation level of the RPV might be reduced enough to allow it to be disposed of as LSA material. The cladding could be removed with the vessel filled with water. This type of operation would require the design and manufacture of a large, inside diameter mounted milling machine. The machine would be lowered into the vessel and supported by hydraulically actuated spider assemblies positioned above and below the cutting spindle.

As with any underwater work, water filtration and vision systems will be required. The chips generated from the machine process are relatively large and will quickly settle to the bottom of the vessel. The chips would have to be airlifted or vacuumed from the lower head periodically.

ALARA APPROACH

Personnel exposure during removal and segmentation operations will vary with the alternate employed. The activities associated with each removal alternate were defined and personnel exposure was estimated to compare exposure **on a relative basis**. The estimated person-rem provided below are not absolute and should only be considered to compare alternates.

The activities that were included in this comparative analysis are those that are unique to each alternate or that are common, but are dose intensive. The major activities considered included:

1. Operation of the cavity water filtration system
2. Steam dryer removal
3. Steam separator removal
4. Core shroud segmentation and packaging
5. Guide tube and tie rod segmentation and packaging
6. GTCC segmentation and packaging
7. Insulation removal
8. Nozzle cuts
9. Plug/shield nozzles
10. RPV sectioning
11. RPV segmentation
12. RPV cover plate installation and rigging
13. RPV intact lift and down-ending

The basis for exposure estimates for each of these activities included manpower loadings for major activities and estimates of the radiation fields in which crews would be performing the activity.

This information was used to prepare separate estimates for each of the major activities. These estimates do not account for reductions from primary system chemical decontamination, which would not affect the results on a relative basis.

Plant specific source terms were used to estimate radiation fields at and around the intact and segmented reactor vessel. These were used to estimate the personnel exposure for activities 8 through 13.

Comparison of Results

Table II summarizes the results in person-rem for each option and activity. As shown, the option leading to maximum exposure is 194 person-rem from complete RPV and internals segmentation. The minimum exposure is 43 person-rem from intact removal through the Drywell.

The major difference between options is the exposure resulting from GTCC internals segmentation. It should be noted that the internals segmentation work may also be required for the intact removal scenarios to gain approval for disposal at Barnwell. Totals for estimated exposure, including GTCC internals segmentation and packaging for the intact scenarios, are also shown in Table II. With the additional exposure from GTCC segmentation and packaging assessed to the intact scenarios, the total exposures for intact versus sectioned removal are within the statistical accuracy of the results. Based on these results, the decision regarding intact versus segmented removal will be driven by cost and schedule and not by personnel exposure.

Table II - Comparative Personnel Exposures
(Person-rem)

Method	Intact Through The Roof Alt. 1	Intact Through The Wall Alt. 2	Intact - Lower Drywell Alt. 3	Upper Into Lower Alt. 4	Horiz. Rings Alt. 5	Short Vert. Sections Alt. 6	Segmented Alt. 7
Totals without GTCC Segmentation	43	44	45	136	145	130	194
Totals with GTCC Segmentation	122	123	124	n/a	n/a	n/a	n/a

COST AND SCHEDULE ESTIMATES

The cost of removal and/or segmentation of the RPV will vary with the alternate employed. The activities associated with each removal alternate were defined and estimated to compare cost **on a relative basis**. The estimates provided in this section are not intended to reflect the total cost to remove the RPV and should only be considered to compare alternates.

Major Activities Included in the Cost Estimate

The major activities included in the estimates are:

- Heavy Lift Equipment and Rigging
- RPV nozzle closure and lift plates
- Removal of Internals
- RPV cutting or segmentation
- Structural modifications and reinforcement
- Engineering

Common Activities Not Included in the Cost Estimate

The following activities are common to all alternates and are not included in the estimates:

- Establish spent fuel pool island
- Install temporary cover over spent fuel pool
- Removal and disposal of Drywell head
- Removal and disposal of Reactor head
- Operation and maintenance of a equipment pool water filtration system
- Removal and disposal of steam dryer
- Removal and disposal of RPV insulation
- Nozzle cuts
- Snubber removal and removal of skirt bolts

Cost Estimates

Table III summarizes the relative costs of the non-common activities for each alternate and major activity. The alternate with the lowest cost is Alternate 2, Intact Removal Through The Wall. The alternate with the highest cost is Alternate 7, RPV Segmentation.

It should be noted that Alternates 1, 2 and 3 reflect intact removal with the lower internals remaining in the RPV. If it is necessary to remove the lower internals prior to shipment, the total cost of each alternate would be increased.

Table III - RPV Removal Alternates Cost Summary (Cost, $1000's)

Activity	**Intact Through The Roof Alt. 1**	**Intact Through The Wall Alt. 2**	**Intact Through Lower Drywell Alt. 3**	**Upper Sections Into Lower Alt. 4**	**Horiz. Rings Alt. 5**	**Short Vert. Sections Alt. 6**	**Segmented Alt. 7**
Heavy Lift Equipment, Rigging & Closure Plates	3,270	2,360	2,380	3,770	60	1,750	900
Remove or Cut Lower Internals into Sections	130	130	130	8240	15,540	13,970	26,770
Reactor Building Structural Modifications	180	130	650	n/a	n/a	n/a	n/a
Engineering	560	560	570	600	280	280	280
Estimated Differential Cost (Total)	$4,140	$3,180	$3,730	$12,610	$15,880	$16,000	$27,950

Common Schedule Assumptions

- RPV removal work begins upon plant shutdown.
- RPV nozzle insulation is removed while reactor cavity is flooded to take advantage of addition shielding offered by the water.
- The following items are to be performed in parallel with the establishment of the spent fuel pool island:
- Design of equipment pool water filtration system
- Design and testing of the cutting system for steam dryer and separator
- Design of the cavity water filtration system
- Development of the RPV rigging plan
- RPV upper and lower internal components, including greater than class "C" (GTCC) material, will be removed. There is an option within Alternates 1 through 3 that the lower internal components will not need to be removed. By not removing the GTCC components, there will be a reduction in schedule duration.

- A license amendment, should one be required, will not comprise a critical schedule path to RPV removal.
- Durations used in the schedules are consistent with what was used for the dose assessment and the comparative cost estimates for all alternates.

Schedule Development

In development of the schedules, the work is broken down into three phases:

- Phase 1 covers all design and preparatory work and ends when the Drywell head is removed from covering the reactor head.
- Phase 2 begins with the removal the reactor head and ends when the CRD tube grouting starts.
- Phase 3 begins with the grouting of the CRD tubes and the snubbers are removed and ends with the removal of the RPV from the Reactor Building.

Establishing the spent fuel pool island will be the first activity that will be performed. In parallel with this, the engineering design of the major filtration, cutting, and rigging system will take place. While the reactor cavity is flooded with water, the RPV nozzle insulation will be removed. This activity is done early in order to take advantage of the extra shielding protection the cavity water offers.

Once the spent fuel pool island is established and the temporary spent fuel pool cover is installed, removal of interfering piping, equipment, and ductwork will be performed. During this time, the Drywell head and reactor head will be removed and disposed. Outside of the facility, activities to support the protection of any underground utilities and outside rigging site work will be performed.

All schedule alternatives will remove the Drywell head, reactor head, steam dryer, and steam separator. Once the steam separator is removed, the installation and testing of the reactor internal component cutting system will take place. Upon completion of the testing, the remainder of the top down dismantling approach will be completed.

In conjunction with the RPV preparation activities, the building will be prepared for the rigging path selected. For Alternate 1, the roof will be opened and a temporary cover installed. Concerning Alternate 2, the Reactor Building wall is opened and the lifting system is installed. With Alternate 3, the building shoring activities, tunneling, and runway systems will be accomplished.

The rigging support activities will start upon the completion of the RPV preparation. If the internal components are being removed, the rigging activities will start at the completion of the disposal of the GTCC components. If the internal components are being contained in the RPV, the rigging activities will start upon the removal of the steam separator from the RPV.

Alternate 4 is the sectioning of the RPV which reduces the volume of the RPV for disposal. If the sectioning alternate is used, all internal components must be removed from the RPV. The Alternate 4 schedule illustrates the effect that internals segmenting has when applied in conjunction with Alternate 3 (removal through the lower Drywell). Generally this alternate will increase the overall schedule (with internal components removed) duration by 75 days.

A summary of schedule durations for the alternates is provided in Tables IV and V.

Table IV - Schedule Durations with Lower Internals Removed (Duration, days)

	Intact Through The Roof Alt. 1	Intact Through The Wall Alt. 2	Intact Through Lower Drywell Alt. 3	Upper Sections Into Lower Alt. 4	Horiz. Rings Alt. 5	Short Vert. Sections Alt. 6	Segmented Alt. 7
Schedule Phase 1	229	229	229	229	229	229	229
Schedule Phase 2	328	328	328	328	328	328	328
Schedule Phase 3	112	105	127	183	134	274	351
Overall Duration	670	664	687	744	691	831	908

Table V - Schedule Durations with Lower Internals Retained in the RPV (Duration, days)

	Intact Through The Roof Alt. 1	Intact Through The Wall Alt. 2	Intact Through Lower Drywell Alt. 3	Upper Sections Into Lower Alt. 4	Horiz. Rings Alt. 5	Short Vert. Sections Alt. 6	Segmented Alt. 7
Schedule Phase 1	229	229	229	n/a	n/a	n/a	n/a
Schedule Phase 2	49	49	49	n/a	n/a	n/a	n/a
Schedule Phase 3	113	106	162	n/a	n/a	n/a	n/a
Overall Duration	391	384	440	n/a	n/a	n/a	n/a

CONCLUSIONS AND RECOMMENDATIONS

Tables VI and VII summarize the results of the estimates made in the study. Note that the exposure and cost values in Tables VI and VII are comparative values - activities common to all removal alternates were not estimated as they would not influence the selection of the best alternate. In the case of load handling risk, a judgement is made regarding whether the spent fuel pool is endangered by lifting operations performed in its proximity.

Table VI - Summary of Results
Remove and Segment Lower Internals

	Intact – Through The Roof Alt. 1	**Intact - Through The Wall Alt. 2**	**Intact - Lower Drywell Alt.3**	**Upper Into Lower Alt. 4**	**Horiz. Ring Sections Alt. 5**	**Short Vert. Sections Alt. 6**	**Segmented Alt. 7**
Exposure Estimate (Person-rem)	122	123	122	136	145	130	194
Cost Estimate ($1000s)	10,780	9,820	10,370	12,610	15,880	16,000	27,950
Schedule Duration (days)	670	664	687	744	691	831	908
Load Handling Risk	Moderate	Moderate	Low	Low	Low	Low	Low

Table VII - Summary of Results
Leave Lower Internals Inside RPV

	Intact – Through The Roof Alt. 1	**Intact - Through The Wall Alt. 2**	**Intact - Lower Drywell Alt. 3**	**Upper Into Lower Alt. 4**	**Horiz. Ring Sections Alt. 5**	**Short Vert. Sections Alt. 6**	**Segmented Alt. 7**
Exposure Estimate (Person-rem)	43	44	43	n/a	n/a	n/a	n/a
Cost Estimate ($1000s)	4,140	3,180	3,730	n/a	n/a	n/a	n/a
Schedule Duration (days)	391	384	440	n/a	n/a	n/a	n/a
Load Handling Risk	Moderate	Moderate	Low	n/a	n/a	n/a	n/a

Radiological Exposure: If the lower internals are removed from the vessel, personnel exposure will be about the same for all of the alternates, with Segmentation being approximately 1/3 higher than the rest. If the lower internals are left inside the RPV, all three of the Intact alternates are about equally favorable.

Cost: If the lower internals are removed from the vessel, the Intact alternates are the most favorable. The Sectioning alternates are only a little more costly. Segmentation, however, is much more costly that any of the other alternates. If the lower internals are left inside the RPV, the Intact alternates are substantial more favorable that any of the other alternates.

Schedule: If the lower internals are removed from the vessel, the Intact alternates are the most favorable. The Sectioning and Segmentation alternates require only a little more time. If the lower internals are left inside the RPV, the Intact alternates are substantial more favorable that any of the other alternates.

Load Handling Risk: The Through-The-Roof and the Through-The-Wall alternates have more risk than the other alternates since they require lifting the RPV near the spent fuel pool. Their risk could be mitigated through load drop analyses. Intact Through-The-Lower-Drywell and the Sectioning and Segmenting alternates have lower risk as they could use single failure proof lifting devices or follow existing safe load paths.

Best Methods: Based on the results of the evaluations performed in this study, the best method for removing the RPV is judged to be Intact Removal Through The Lower Drywell, Alternate 3. The second-best alternative is Sectioning Into Short Vertical Sections, Alternate 6.

Intact Removal Through The Lower Drywell is judged to be the best alternate because its dose, cost and schedule duration are the most favorable of all alternates studied. This method also offers a means of eliminating the risk to the spent fuel pool (by employing a single failure proof rigging system). Further, this alternate retains the opportunity to leave the lower internals inside the vessel, which has the value of substantially reducing the dose, cost and schedule duration. None of the other alternates offers this combination of attributes and opportunities.

Sectioning into Short Vertical Sections is the next best alternate. This alternate retains the low risk from to load handling while requiring only slightly more dose and schedule time. Cost is the primary disadvantage of this method relative to Alternate 3 with internals removed. Because this method requires segmentation of the RPV shell as well as of the internals, it is a more costly option. However, it has the advantages of being able to use the existing Reactor Building crane rather than erecting a new lifting system and results in smaller pieces than Alternate 3 providing more flexibility in shipment methods.

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- NRC Bulletin 96-02, "Movement of Heavy Loads over Spent Fuel, Over Fuel in the Reactor Core, or Over Safety-Related Equipment," April 11, 1996.
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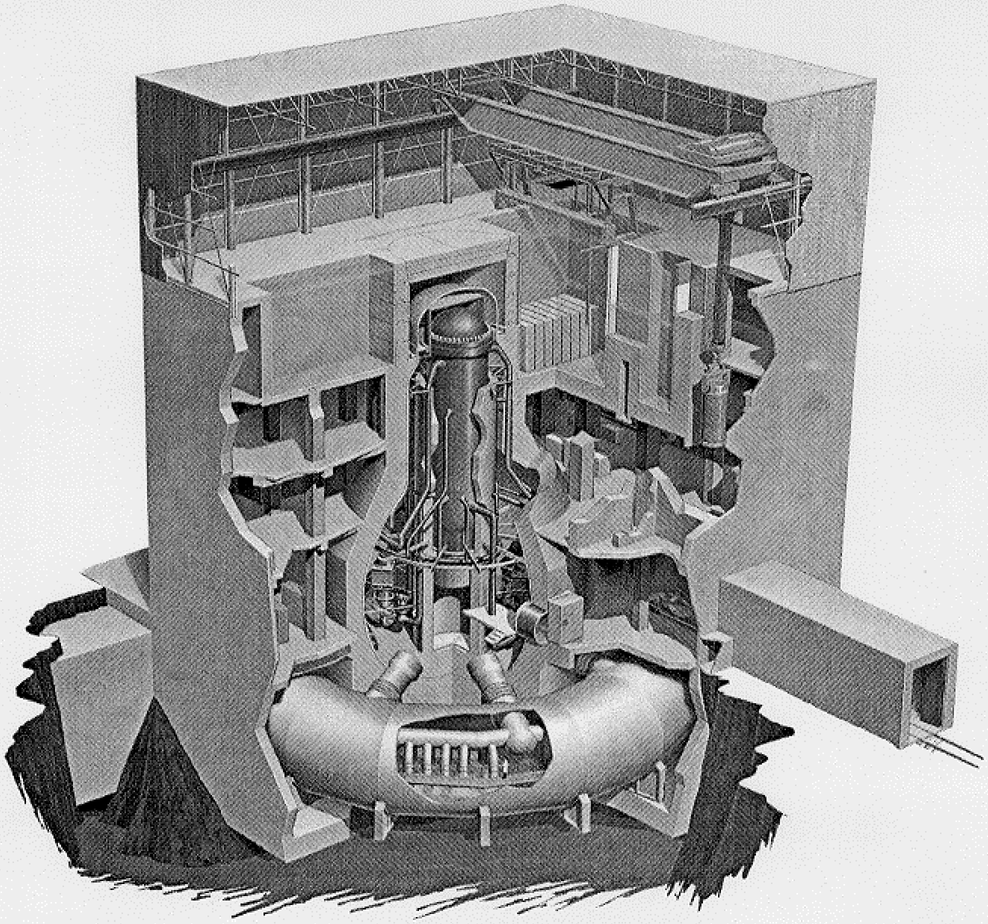
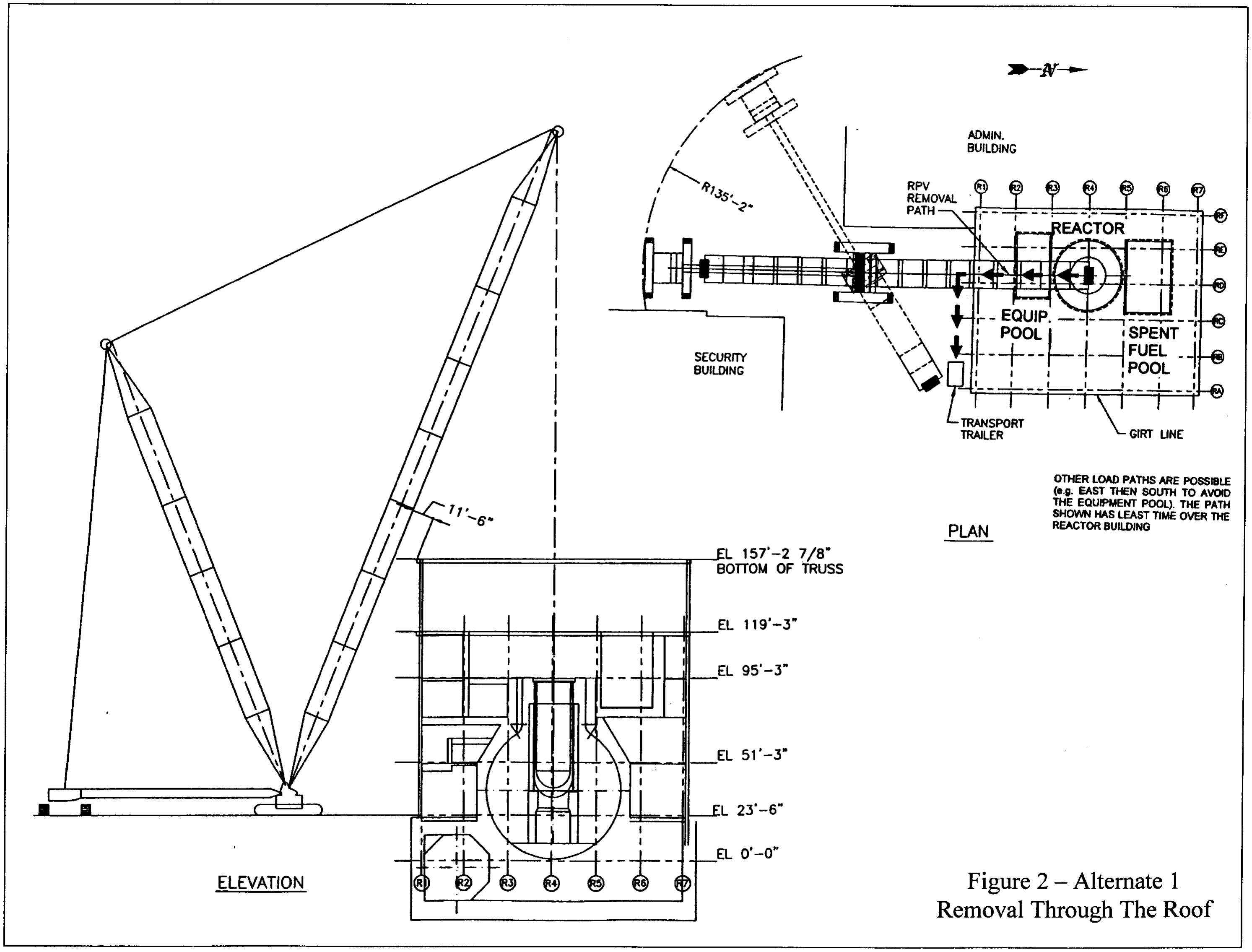


Figure 1 – GE Boiling Water Reactor System



OTHER LOAD PATHS ARE POSSIBLE (e.g. EAST THEN SOUTH TO AVOID THE EQUIPMENT POOL). THE PATH SHOWN HAS LEAST TIME OVER THE REACTOR BUILDING

Figure 2 – Alternate 1
Removal Through The Roof

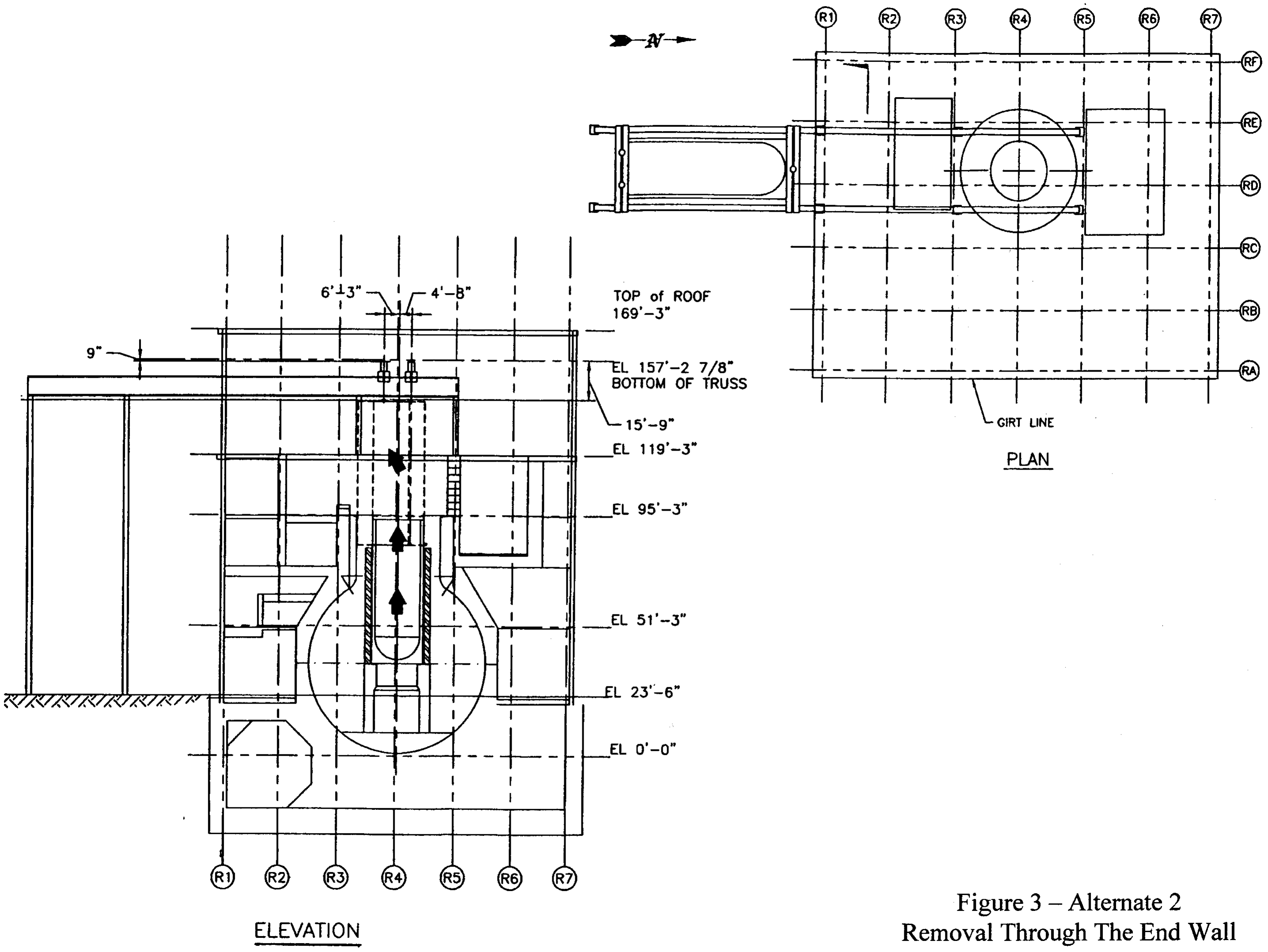


Figure 3 – Alternate 2
Removal Through The End Wall

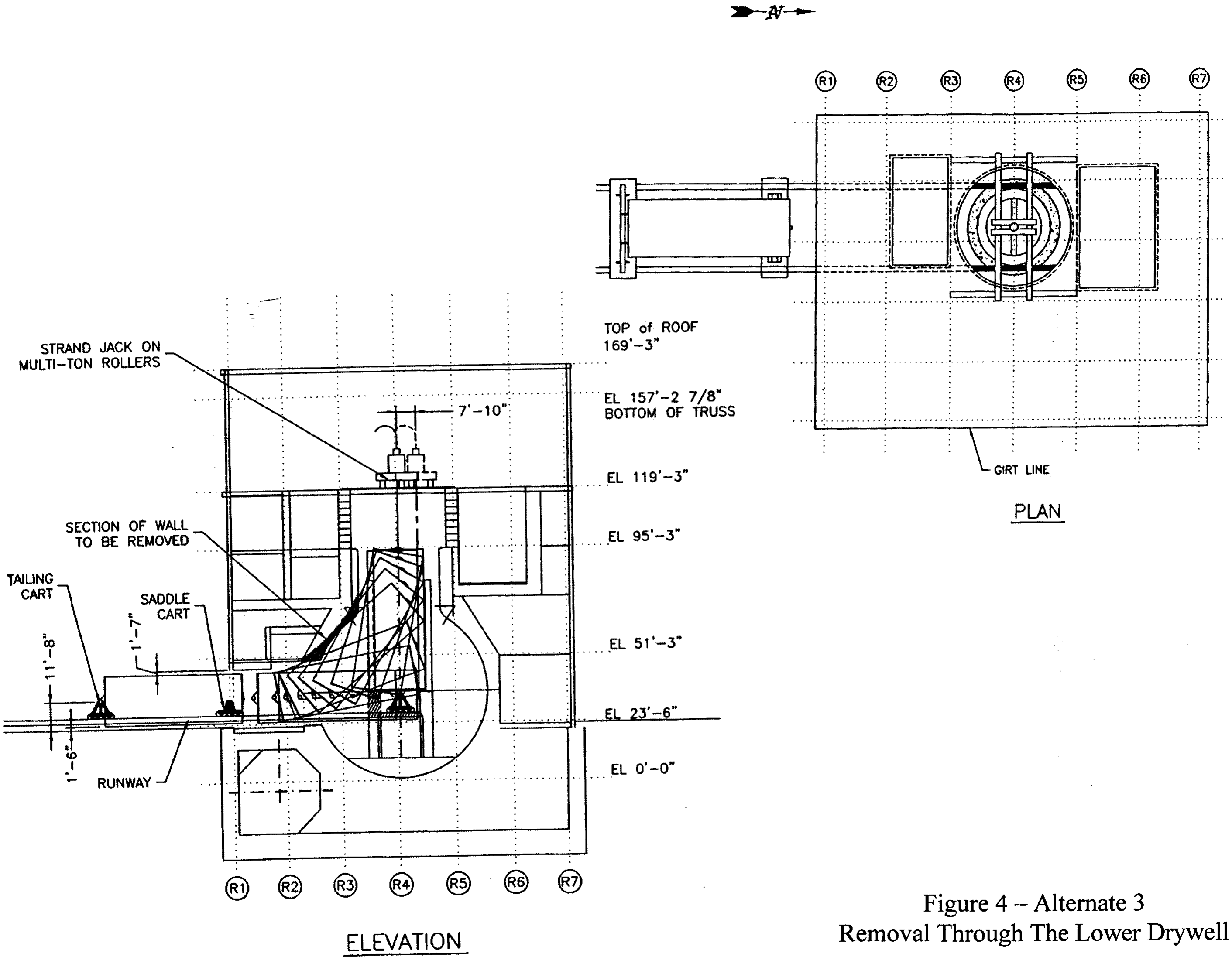


Figure 4 – Alternate 3
Removal Through The Lower Drywell

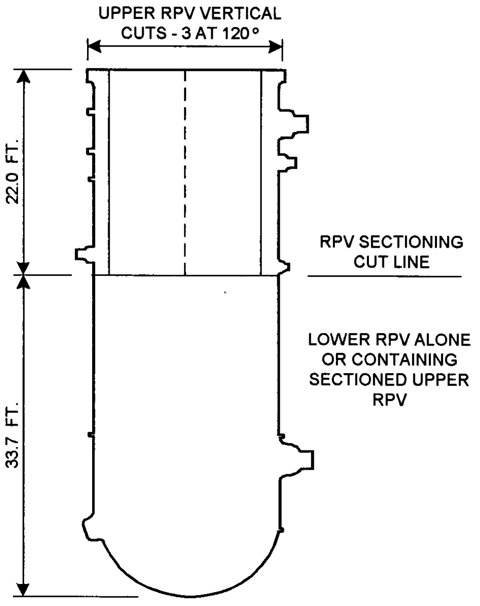


Figure 5 - Alternate 4 Sectioning Scheme

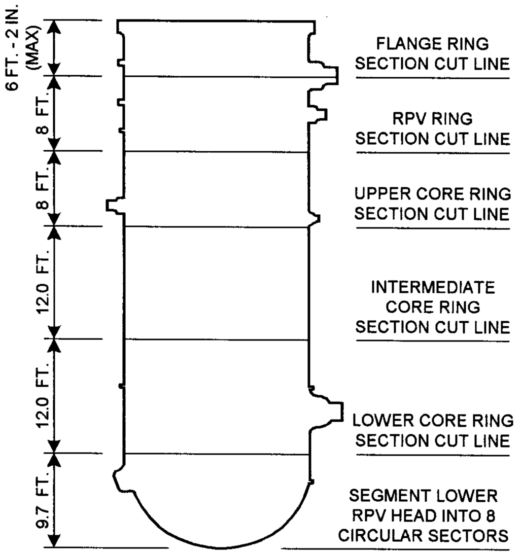


Figure 6 - Alternate 5 Sectioning Scheme

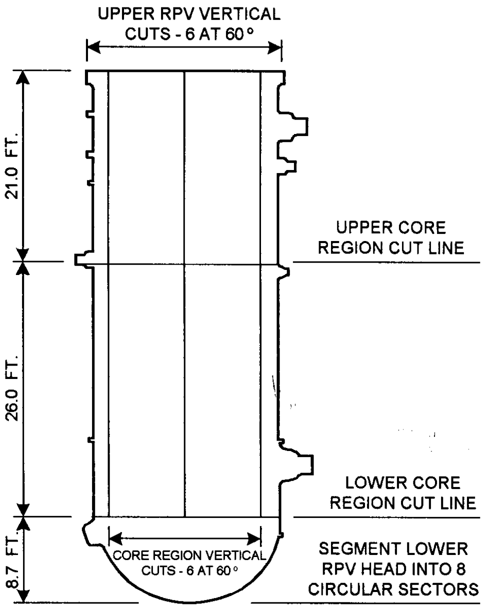


Figure 7 - Alternate 6 Sectioning Scheme

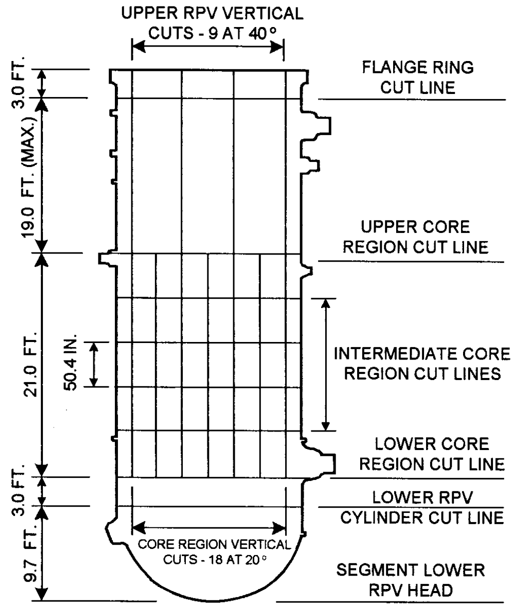


Figure 8 - Alternate 7 Segmentation Scheme