

# **Statement of Work for the Acquisition of Zion Unit 2 Reactor Pressure Vessel Segments**

**September 2014**

**Prepared by**

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Light Water Reactor Sustainability Program

## **Statement of Work for the Acquisition of Zion Unit 2 RPV Segments**

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## **EXECUTIVE SUMMARY**

The decommissioning of the Zion Units 1 and 2 Nuclear Power Plants (NPP) in Zion, Illinois presents a special and timely opportunity for developing a better understanding of materials degradation and other issues associated with extending the lifetime of existing nuclear power plants beyond 60 years of service. In support of extended service and current operations of the US nuclear reactor fleet, the Oak Ridge National Laboratory (ORNL), through the Department of Energy (DOE), Light Water Reactor Sustainability (LWRS) Program, is coordinating and contracting with Zion Solutions, LLC, a subsidiary of Energy Solutions, an international nuclear services company, the selective procurement of materials, structures, components, and other items of interest from the decommissioned reactors as well as possible access to perform limited on site testing of certain structures and components.

The LWRS Program, the Electric Power Research Institute (EPRI) Long-Term Operation (LTO) Program, and other interested research organizations (e. g., the U.S. Nuclear Regulatory Commission) wish to acquire materials from the Zion nuclear power plants (NPP) to support extended lifetime of existing nuclear power plants. This report describes the plan to acquire two segments of the Zion NPP Unit 2 RPV. Specifically, harvest one section of the SA-1769 beltline weld with a WF-70 vertical weld and an adjoining section that includes a section of the SA-1769 beltline weld but no vertical weld. This second section containing the beltline weld is expected to have the highest radial fluence. Access to service-irradiated RPV welds and plate sections will allow through-wall attenuation studies to be performed, which will be used to assess current radiation damage models.

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# 1. INTRODUCTION

**Background:** The decommissioning of the Zion Units 1 and 2 Nuclear Power Plants (NPP) in Zion, Illinois presents a special and timely opportunity for developing a better understanding of materials degradation and other issues associated with extending the lifetime of existing nuclear power plants beyond 60 years of service. In support of extended service and current operations of the US nuclear reactor fleet, the Oak Ridge National Laboratory (ORNL), through the Department of Energy (DOE), Light Water Reactor Sustainability (LWRS) Program, is coordinating and contracting with Zion Solutions, LLC, a subsidiary of Energy Solutions, an international nuclear services company, the selective procurement of materials, structures, components, and other items of interest from the decommissioned reactors as well as possible access to perform limited on site testing of certain structures and components. It is understood that the process of obtaining materials or access cannot and will not result in any delays to Zion Solutions' critical path for decommissioning Zion 1 and Zion 2 NPP.

The LWRS Program, the Electric Power Research Institute (EPRI) Long-Term Operation (LTO) Program, and other interested research organizations (e.g. the U.S. Nuclear Regulatory Commission) wish to acquire materials from the Zion nuclear power plants (NPP) to support extended lifetime of existing nuclear power plants. This request focuses on acquiring segments of the Zion Unit 2 Reactor Pressure Vessel (RPV) for laboratory testing. Access to service-irradiated RPV welds and plate sections will allow through-wall attenuation studies to be performed, which will be used to assess current radiation damage models. [1]

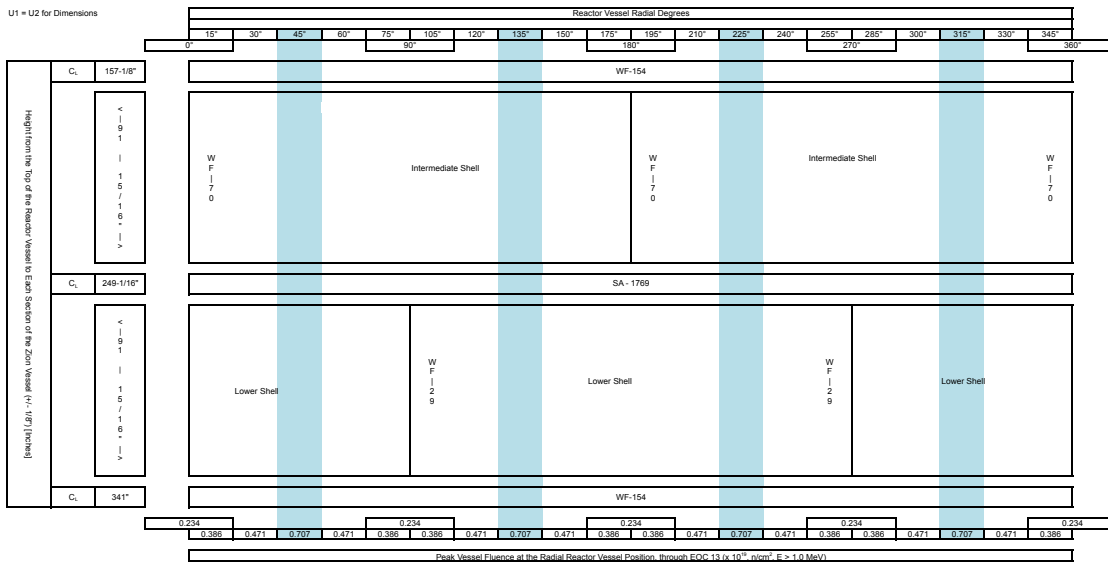


Figure 1. Peak vessel fluence at the radial reactor pressure vessel position through EOC 13 ( $\times 10^{19}$  n/cm<sup>2</sup>, E > 1.0 MeV)

**Radial Fluence:** An important consideration in the evaluation of which RPV sections to harvest is the radial fluence. As shown at the bottom of Fig.1, peak radial fluence varies by a factor of three over a 45° arc segment from the vertical weld positions to midway between the vertical weld positions. Based on this variation, the optimum section of beltline weld to harvest would be a section midway between the vertical welds.

**RPV Specifications:** The Zion RPV has a total height without the head plate of approximately 419 inches. The vessel wall has an inner diameter of 173 inches and thickness of 8.8 inches over the beltline region. The nozzle section is approximately 11 inches thick. Including cladding, the reactor vessel weighs about 700,000 lbs. and has a total activity of about 400 curies. The characterization results indicate that the vessel wall is class A waste.

The stainless steel cladding has a nominal thickness of 3/16 inch. The total weight of the cladding within +/- 2 feet of the core is about 4,750 lbs. and has a total activity of approximately 145 curies. If it were separate from the vessel wall, the cladding would be class B waste, but if it is integral with the wall, the assembly as a whole is class A. The RPV is composed of the head, nozzle ring section, three ring or shell sections composed of hemispherical plates with two vertical welds, and a bottom plate (Fig 2).

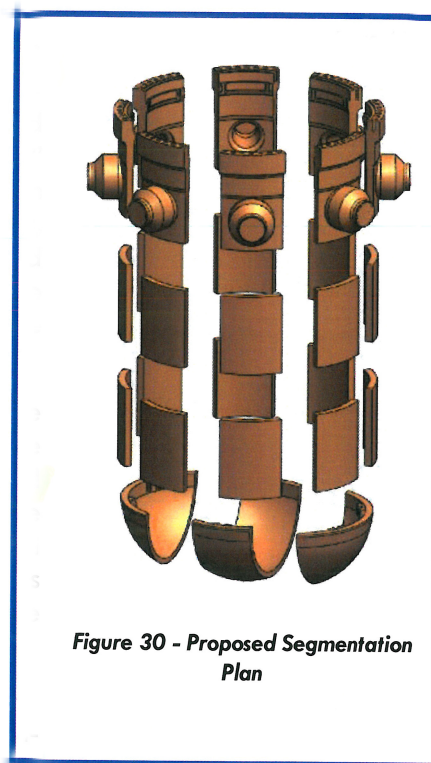
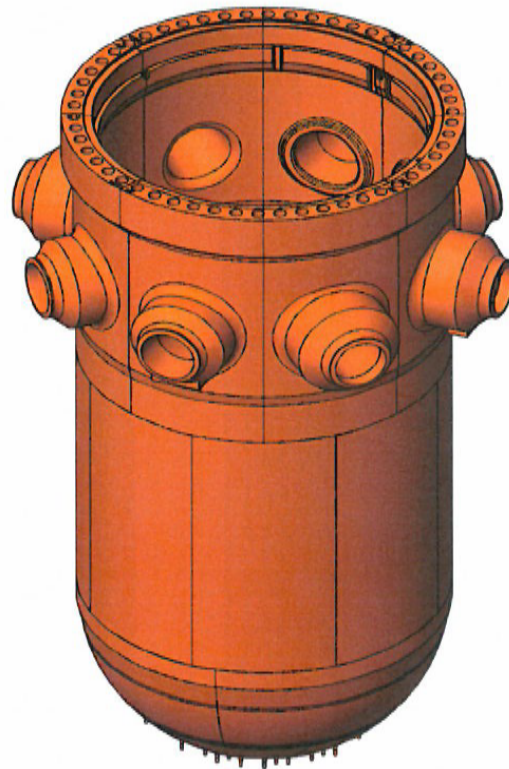


Figure 2. Schematic of the RPV segmented by ring sections and the bottom plate



Reactor Pressure Vessel  
Isometric View

Figure 3. Schematic of the 2014 RPV segmentation Plan

## 2. CUTTING PLAN

**Current Cutting Plan:** Based on information provided by Mr. Dan E. Pryor, Manager, Reactor Vessel Segmentation, Zion Solutions, the vessel will be cut, using an oxy-propane torch into 22 segments over four levels (Figs 3 and 4). Level 1, which includes the inlet and outlet nozzles, will be cut into eight 45° segments of 157.5" in height. Level 2 will also be cut into eight 45° segments of 157.5" in height and 72.9" in length as measured from end to end of the outer diameter. These segments will include most of the intermediate and lower shells and each segment will include a portion of the beltline weld. Two of the segments will include the WF 70 vertical weld of the intermediate shell, two will include the WF 29 vertical weld of the lower shell, and four will not include any vertical weld (Figs. 4 and 5). The beltline pieces under the current Zion segmentation plan will be 8.8 inches thick including a 3/16 inch stainless steel cladding on the internal surface. Each piece will weigh approximately 28,000 lbs.

Since the Level two cuts are expected to occur at elevations 157.5" and 315", or from just below the circumferential weld of the upper and intermediate rings and just above the radial guides on the inside of the vessel that will be used to support the vessel during segmentation, there will be no thermal damage to the beltline weld or heat-affected zone from the horizontal cuts. Based on the current schedule, Zion Solutions will generate the desired segments from Unit 2 between October 2014 and January 2015. During the next 3 - 6 months, a suitable receipt and storage facility will be selected.

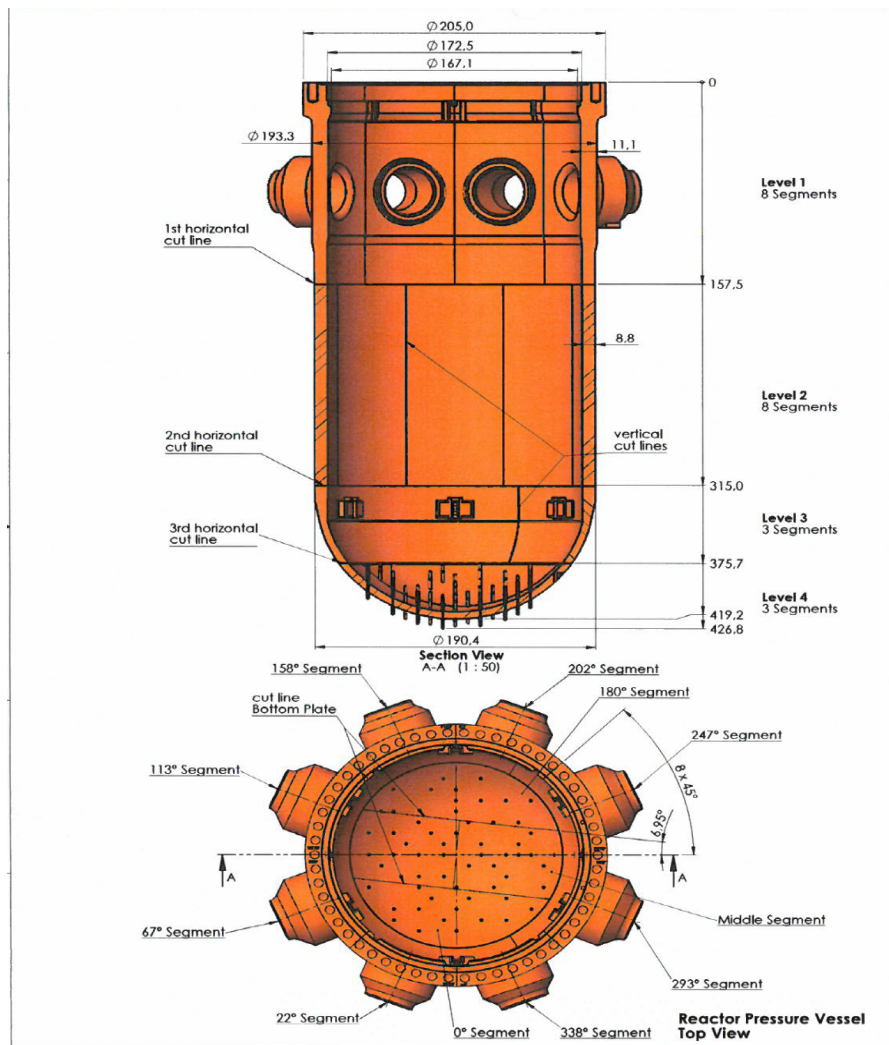


Figure 4. Current RPV segmentation plan for the Zion Unit 2 vessel. The black lines are the proposed cut plan. There are eight vertical cuts in the nozzle region and eight vertical cuts in the vessel wall area.



## Location and Identification of Materials Used in the Fabrication of Zion Unit 2 Reactor Pressure Vessel

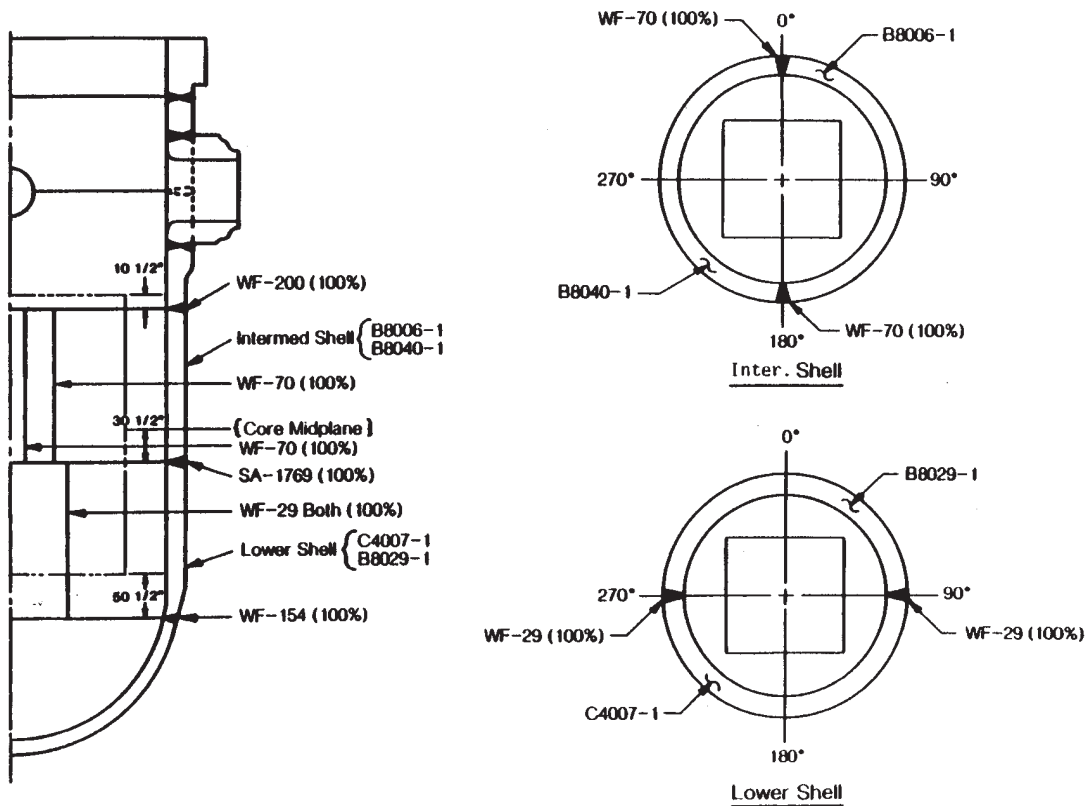


Figure III.1.1-2

Figure 5. Materials used in beltline (intermediate shell) and vertical welds above the beltline

### 3. OBJECTIVES, SCOPE, AND TASKS

**Objectives:** The objective of this work is to obtain two segments of the Zion NPP Unit 2 RPV. Specifically, harvest one section of the SA-1769 beltline weld with a WF-70 vertical weld and an adjoining section that includes a section of the SA-1769 beltline weld but no vertical weld (Figs. 3, 4, and 6). This second section containing the beltline weld is expected to have the highest radial fluence.

**Scope:** Harvest a beltline and a beltline and intermediate shell vertical weld segments from the Zion Unit 2 RPV.

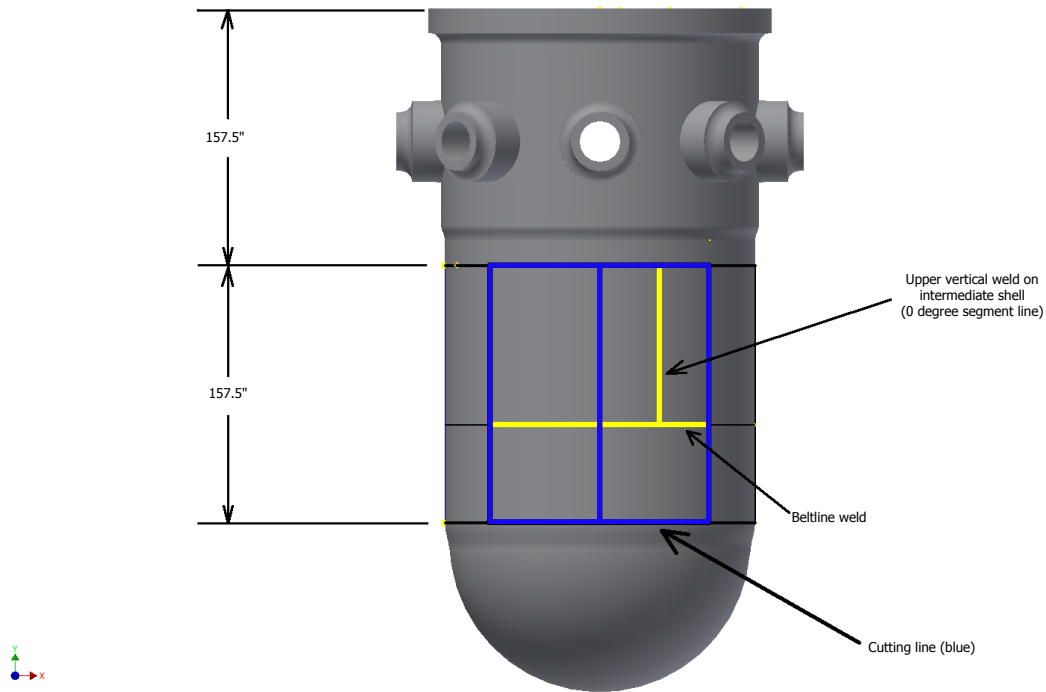


Figure 6. Identification of two Level 2 segments to be harvested. The WF-70 vertical weld with the beltline weld from the segment centered at 0° or 180° and an adjacent segment with only the beltline weld.

**Task 1: Beltline and Vertical Weld Segments:** One section of the RPV extending from the intermediate shell into the lower shell that includes the SA-1769 beltline weld and a WF-70 vertical weld (Figs. 4, 5, and 6) will be harvested from the Zion Unit 2 RPV. Data from surveillance specimens containing similar SA-1769 and WF-70 weld materials are available in the literature for a comparison of hardening and changes in fracture toughness.

1. Cut one section ~ 13' x 6' (157.5" x 72.9" x 8.8") of the RPV extending from just below the circumferential weld between the nozzle section and the intermediate shell to just above the circumferential weld between the lower shell and the bottom plate. This section **includes the SA-1769 beltline weld and a centered WF-70 vertical weld**. This section as identified in Figs 1, 5 and 6 can be obtained from either the 0° or at 180° segments.
2. Package the RPV section in the manner used to ship the other RPV sections to the Energy Solutions, Clive, Utah site and transfer to either a rail car or intermodal container for shipment to the Energy Solutions, Memphis site (c/o Director of Operations) or other designated location.

**Preliminary Test Plans:** After removing the cladding, the large section of the RPV segment containing the beltline SA-1769 and vertical WF-70 welds, will be machined into test specimens including Charpy V-Notch (CVN), tensile, and fracture toughness, from the Linde 80 (weld wire 72105) weld and WF-70 weld, both having a peak fluence  $< 1 \times 10^{19} \text{ n/cm}^2$ , at the Memphis Energy Solutions site or other suitable location. The specimen dimensions will be as follows:

- CVN (Charpy V-Notch) / Size: 10 x 10 x 55 mm
- Tensile / Size: 10 x 10 x 55 mm or smaller, and
- Fracture toughness (compact tension) / Size:  $\frac{1}{2}$ -T C(T)

In addition to specimens for mechanical testing, two sections containing the through thickness weld will be obtained to perform through-thickness chemical characterization (at least, Cu, Ni, Mn, P), hardness distribution, and various microstructural characterization techniques such as Atom Probe Tomography (APT), Small Angle Neutron Scattering (SANS), and Positron Annihilation Spectroscopy (PALS).

The test plans are as follows:

- (1) Determine through-thickness variation in chemical composition (especially Cu).
- (2) If the chemical composition, especially the Cu content, is relatively uniform, perform CVN and tensile tests and compare with surveillance results.
- (3) Perform CVN, tensile, and  $K_{Jc}$  testing through thickness to evaluate attenuation effects. (The Zion 2 weld metal showed a Charpy 41-J shift of 225°F at  $1.5 \times 10^{19}$  n/cm<sup>2</sup>.)
- (4) Similar testing through the thickness of base metal is not recommended at this time, but may be considered if such testing of the weld metal is not performed. However, because of the increased height of the vessel segment relative to the preliminary cutting plan from Zion Solutions, there may be an opportunity to evaluate flux effects in the base metal between the region near the beltline weld and the upper region of the segment.

Thermal annealing of these RPV materials may also be performed to compare with the same weld metal (WF-70) previously irradiated in test reactors and annealed.

**Task 2: Beltline Segment:** One Level 2 section of the RPV extending from the intermediate shell into the lower shell that **includes the SA-1769 beltline weld** (Figs. 4 and 5) that is adjacent to the section harvested in Task 1. It should not contain a vertical weld from either the intermediate or bottom shell.

1. Cut one section ~ 13' x 6' (157.5" x 72.9" x 8.8") of the RPV extending from just below the circumferential weld between the nozzle section and the intermediate shell to just above the circumferential weld between the lower shell and the bottom plate that is adjacent to the section harvested in Task 1. This section **includes only the SA-1769 beltline weld and no vertical weld**. This section as identified in Figs 1 and 5 can be obtained from either the 45° or 315° segments if the segment at 0° was selected in Task 1 or from either the 135° or 225° segments if the segment at 180° was selected in Task 1.
2. Package the RPV section in the manner used to ship the other RPV sections to the Energy Solutions, Clive, Utah site and transfer to either a rail car or intermodal container for shipment to the Energy Solutions, Memphis site (c/o Director of Operations) or other designated location.

**Preliminary Test Plans:** After removing the cladding, the large section of the RPV segment containing only the beltline SA-1769 weld, will be machined into test specimens including Charpy V-Notch (CVN), tensile, and fracture toughness, from the Linde 80 (weld wire 72105) weld having a peak fluence  $< 1 \times 10^{19}$  n/cm<sup>2</sup>, at the Memphis Energy Solutions site or other suitable location. The specimen dimensions will be as follows:

- CVN (Charpy V-Notch) / Size: 10 x 10 x 55 mm
- Tensile / Size: 10 x 10 x 55 mm or smaller, and
- Fracture toughness (compact tension) / Size:  $\frac{1}{2}$ -T C(T)

In addition to specimens for mechanical testing, two sections containing the through thickness weld will be obtained to perform through-thickness chemical characterization (at least, Cu, Ni, Mn, P), hardness distribution, and various microstructural characterization techniques (at least APT, SANS, PALS).

The test plans are as follows:

- (1) Determine through-thickness variation in chemical composition (especially Cu).
- (2) If the chemical composition, especially the Cu content, is relatively uniform, perform CVN and tensile tests and compare with surveillance results.
- (3) Perform CVN, tensile, and  $K_{Ic}$  testing through thickness to evaluate attenuation effects. (The Zion 2 weld metal showed a Charpy 41-J shift of 225°F at  $1.5 \times 10^{19}$  n/cm<sup>2</sup>.)
- (4) Similar testing through the thickness of base metal will be performed as well.

Thermal annealing of these RPV materials may also be performed to compare with the same weld metal (WF-70) previously irradiated in test reactors and annealed.

#### 4. NON-DESTRUCTIVE ANALYSIS

**Non Destructive Evaluation of RPV Segments:** Due to the unique opportunity to evaluate large segments of the RPV, non-destructive examination prior to cutting the beltline and vertical weld segments into smaller pieces for machining into mechanical test and microstructural characterization specimens may be performed at the Energy Solutions Memphis (c/o Director of Operations) or other designated location.

#### 5. TRANSPORTATION

**Transportation of Segments:** Due to the size and weight of the two Level 2 beltline sections (157.5" x 72.9" x 8.8" thick including a 3/16 in SS cladding on the internal surface, weighing ~ 28,000 lbs. each), either a rail car or an intermodal container will be used to ship the RPV segments to the Energy Solutions, Memphis site (c/o Director of Operations) or other designated location.

It is anticipated that at this intermediate site, the RPV segments will be evaluated by NDE techniques and cut into smaller sections for machining into mechanical test and microstructural characterization specimens. These smaller sections or test specimens will be shipped to ORNL and could in turn be transferred to user facilities, such as the ATR, universities, research institutes (domestic and foreign), and vendors for testing, characterization, or radiation to higher doses followed by mechanical testing and microstructural characterization.

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## **6. SUMMARY**

This report describes the plan to harvest two segments of the Zion NPP Unit 2 RPV. Specifically, harvest one section of the SA-1769 beltline weld with a WF-70 vertical weld and an adjoining section that includes a section of the SA-1769 beltline weld but no vertical weld. This second section containing the beltline weld is expected to have the highest radial fluence. Access to service-irradiated RPV welds and plate sections will allow through-wall attenuation studies to be performed, which will be used to assess current radiation damage models.

The harvesting of materials from the Zion 1 & 2 NPP, in collaboration with EPRI, the NRC, and the US nuclear industry, will provide invaluable access to materials for which there is little operational data or experience to inform relicensing decisions and, in coordination with other materials tasks, an assessment of current degradation models to further develop the scientific basis for understanding and predicting long-term environmental degradation behavior. This is an opportunity that can't be missed.

## **7. REFERENCE**

1. Rosseel, T. M., Nanstad, R. K., Naus, D., "Harvesting Materials from the Decommissioned Zion 1 & 2 Nuclear Power Plants for Aging Degradation Evaluation," *Trans Am Nucl. Soc.*, **107**, (2012).

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