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Prepared by the
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A Proposal for Sampling the SONGS-1 Reactor Pressure Vessel

R. E. Stoller and R. K. Nanstad
Oak Ridge National Laboratory, Oak Ridge, Tennessee

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A Proposal for Sampling the SONGS-1 Reactor Pressure Vessel

Roger E. Stoller and Randy K. Nanstad
Metals and Ceramics Division
Heavy-Section Steel Irradiation Program
Oak Ridge National Laboratory

Abstract

Validation of the engineering assessment of reactor pressure vessel (RPV) materials through the examination of service-irradiated materials is a critical objective of the Oak Ridge National Laboratory Heavy-Section Steel Irradiation Program, which is sponsored by the U.S. Nuclear Regulatory Commission. The San Onofre Nuclear Generating Station Unit 1 (SONGS-1), which was shut down in 1992, is currently being decommissioned by Southern California Edison. As part of the decommissioning process, the RPV will be removed from the containment building and shipped to Barnwell, South Carolina, for permanent burial. It is proposed that samples of the SONGS-1 RPV be obtained in the form of through-thickness trepans before its disposal in order to provide data on radiation damage attenuation through the RPV and on thermal aging of RPV materials. SONGS-1 operated for a total of 108,550 equivalent full-power hours (12.4 full-power years), resulting in a maximum neutron fluence (E > 1.0 MeV) on the vessel of 4×10^{19} n/cm^2, or about 7×10^{-2} dpa. Thus, the mechanical property data obtained from the SONGS-1 RPV would be relevant to the evaluation of end-of-life properties for the current generation of nuclear power plants and would provide guidance on two critical technical issues related to the revision of the embrittlement correlation in Regulatory Guide 1.99. A number of technical and logistical issues must be resolved relatively quickly in order to complete sampling before the RPV is buried at a disposal site. These issues are discussed, and the preferred options for sampling the SONGS-1 RPV are presented with a preliminary cost estimate for obtaining the required trepans.

Introduction

One of the major unresolved technical issues concerning the embrittlement of nuclear reactor pressure vessels (RPVs) is the degree to which damage is reduced as a function of distance into the RPV. The embrittlement correlation used in the current Regulatory Guide 1.99, Revision 2 (RG-1.99/2) assumes that the radiation-induced increase in the ductile-to-brittle transition temperature (DBTT) at the interior wetted-wall of an RPV can be calculated based on the fast ($E > 1.0$ MeV) neutron fluence [1]. However, because the neutron energy spectrum changes within the RPV, an expression that is approximately related to the local number of displacements per atom (dpa) is used to predict the DBTT shift within the RPV. This leads to a slower attenuation of the DBTT shift than would be calculated based on the local fast fluence.

In addition to a changing neutron energy spectrum, the absolute level of the neutron flux decreases with depth into the RPV. A proposed revision to the current RG-1.99/2 embrittlement correlation [2] includes a term that is implicitly dependent on the neutron flux, with the DBTT shift increasing at lower fluxes. Use of this correlation would lead to a further increase in the predicted DBTT shift at all locations within the RPV. The reduced damage attenuation rate through the RPV would have direct implications for reactor operations because it would affect pressure-temperature limits during reactor start-up and shutdown as well as resulting in the expected consequences of some reactor accident sequences. The proposed correlation [2] also includes a term that adds an additional increment of ~10°C to the DBTT shift if the exposure time exceeds 97,000 h.

The postulated effects of changing the neutron spectrum and neutron flux are based on well-understood physical mechanisms. In contrast, the basis for the increase in DBTT at long times is less well understood but presumably arises from long-term thermal aging in a way that is additive with the effects of irradiation. However, given the nature of the surveillance database (i.e., somewhat accelerated displacement rates relative to the RPV and little variation in the neutron energy spectrum), all of these effects are difficult to discern in the commercial reactor surveillance database. They can only be detected through sophisticated statistical analyses [2], with further confirmation obtained from experiments conducted in materials test reactors. Thus, the opportunity to obtain data from a decommissioned RPV that is representative of typical commercial operating conditions should not be missed.

A limited amount of similar data is available [3–5]. However, the value of that data is diminished, either because the RPVs operated at lower temperatures [3] or because the total fluence was relatively low and the RPV thickness was much less than that of modern PWRs [4,5]. The primary limitation of the SONGS-1 RPV is that it was fabricated from materials in a composition range that is not overly sensitive to radiation because the copper and nickel contents are not high (both are ~0.2 wt %). However, because similar materials were used in the fabrication of other operating RPVs, the data obtained on through-thickness property change and the effect of long-term exposure will be directly relevant to the development and evaluation of embrittlement correlations.

SONGS-1 RPV Operating History and Neutron Exposure

The SONGS-1 began commercial operation in 1968 and was shut down in 1992. During the nearly 25-calendar-year lifetime, the reactor operated for about 12.4 effective full power years

(EFPY) or 108,550 effective full power hours (EFPH). The maximum neutron fluence ($E > 1.0$ MeV) in the beltline region is $\sim 4 \times 10^{19}$ n/cm^2, resulting in an average fast flux of $\sim 1 \times 10^{11}$ n/cm^2/s. The azimuthal variation in the fast fluence is a factor of five at the core centerline. The axial variation from the core centerline is illustrated by the following ratios of local to peak fluence: 0.8, 0.4, and 0.1 at 4, 5, and 5.5 ft from the axial centerline, respectively. The calculated reduction in the fast fluence through the RPV is a factor of 32 [6].

SONGS-1 RPV Chemistry

The SONGS-1 RPV was fabricated from nine plates of A302B materials. The plates were obtained from five similar heats of material produced by Lukens Steel, which was subsequently acquired by Bethlehem Steel. Two plates, one in the core beltline course and the other in the nozzle course, were prepared from Lukens heat A3099 and have the following composition (weight percent): 0.18 Cu, 1.34 Mn, 0.47 Mo, 0.20 C, 0.20 Si, 0.020 S, 0.012 P [7]. The copper content was not included in the original chemical analysis from Lukens; it was obtained from the Power Reactor Embrittlement Database (PR-EDB) [8]. The compositions of the other Lukens plates used in the SONGS-1 vessel were similar [7]. The nickel contents of the Lukens plates were also not in the original alloy certifications, nor has the nickel content of heat A3099 been reported elsewhere. However, the nickel content of one of the companion heats used in the vessel is listed as 0.20 wt % in the PR-EDB [8] and is reported by MCS [2] in an analysis of the database as the "best estimate" nickel value. Such a value is typical for the A302B alloy specification of that time period.

Selection of SONGS-1 RPV Material for Sampling Project

Two plates were prepared from Lukens heat A3099. The vendor that fabricated the pressure vessel for Westinghouse designated the plates as W-7601-6 and W-7601-8. Plate W-7601-6 was used in the nozzle course of the RPV; plate W-7601-8 was incorporated into the beltline course. The active core height is 118 in.; the beltline course weld extends 3⅞ in. below the bottom of the core and ends 10¼ in. below the top of the core. Therefore, the height of the beltline course weld is about 112 in. Given the axial and azimuthal variations in the fluence based on the SONGS-1 operating history, it is feasible to obtain (1) samples from the SONGS-1 RPV at intermediate and high fluences from the plate W-7601-8 and (2) samples from the same heat in W-7601-6 at such a low fluence as to be representative of the unirradiated condition.

The samples from plate W-7601-6 will serve two purposes. First, they will provide the measurement of the original through-thickness variation in the plate's mechanical properties, which will be needed to assess the radiation damage attenuation through the RPV in the irradiated plate. Such data are critically needed to verify the damage attenuation function that is assumed in the current RG-1.99/2 on RPV embrittlement [1]. In addition, these samples will provide valuable data on the effect of long-term thermal aging in RPV materials at the typical commercial RPV operating temperature. These data are relevant to the proposed revision of RG-1.99/2, which imposes an additional increment of DBTT shift for all RPVs that have accumulated more than 97,000 EFPY [2]. This so-called "long-time bias" apparently arises from an unexpected effect of time at operating temperature. However, this term in the proposed embrittlement correlation is based on only a limited amount of data.

Charpy shift data for material irradiated in the SONGS-1 reactor surveillance program are shown in Figures 1 (a) and (b), in which the neutron fluence is plotted on linear and logarithmic scales, respectively. Data for three of the SONGS-1 RPV plates are shown along with data from SONGS-1 A302B correlation monitor material (CMM). The CMM data obtained from the PR-EDB for specimens irradiated in other reactor surveillance programs are also shown for comparison. The plots indicate that data for the SONGS-1 plates are consistent with other A302B data and that the irradiation response of the CMM in SONGS-1 is also typical. For purposes of comparison, the Charpy shifts calculated by using the RG-1.99/2 embrittlement correlation and the revised correlation by Eason, Wright, and Odette (EWO) [2] are also shown for the three surveillance capsule fluences. This comparison also indicates that radiation-induced embrittlement in the SONGS-1 plate material is typical of the larger embrittlement database. Finally, the hardening behavior of the SONGS-1 plate is also in the expected range, with the ratio of the Charpy shift to yield strength change varying between 0.3 and 0.5°C/MPa.

The data shown in Figure 1 and the EWO prediction at a fluence of 4×10^{19} n/cm^2 indicate that the expected DBTT shift for the SONGS-1 plate at the highest fluence position should be about 130°F and that the fluence dependence is relatively weak, between 1.5 and 4×10^{19} n/cm^2. As a result, it is recommended that trepans be obtained from a lower fluence position (between 0.5 and 1×10^{19} n/cm^2) as well as at the highest fluence. The relative attenuation of damage through the RPV will be greater at the lower fluence because of the higher fluence dependence below ~1×10^{19} n/cm^2, and comparing the attenuation at low and high fluence will provide a stronger test of the attenuation function used in RG-1.99/2. Similarly, having data at multiple fluxes and fluences will help evaluate the fluence function used in the embrittlement correlation.

Technical and Logistical Issues Related to Sampling the SONGS-1 RPV

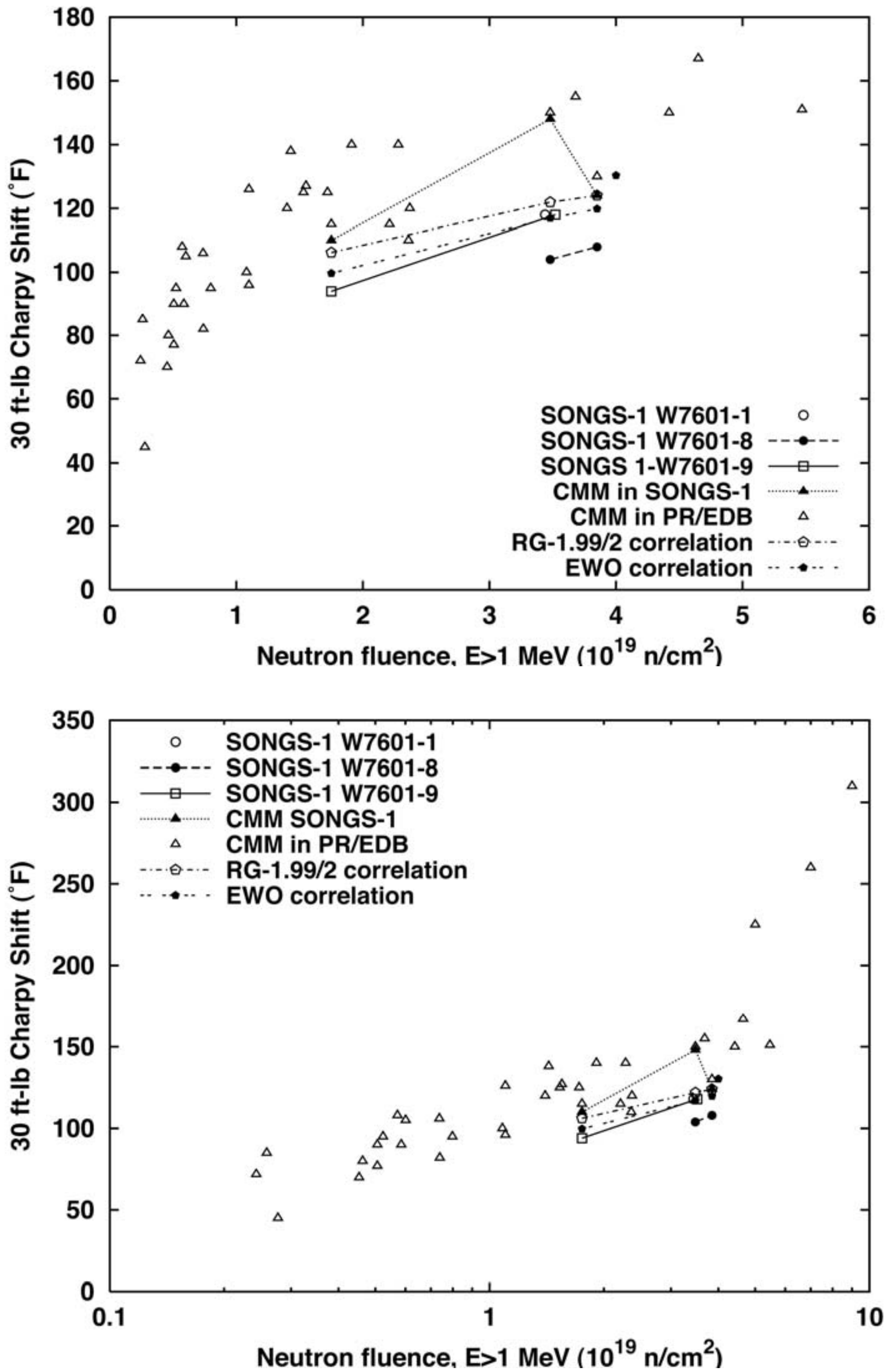
The decommissioning process provides several distinct opportunities for removing samples from the SONGS-1 RPV. These are listed in the first column of Table 1. Discussions held with staff from Southern California Edison (SCE) explored each of these options. Substantial objections can be raised with all of the options in Table 1; however, only a few are listed for each case. The last two options are the only ones that seem feasible. In either case, the sampling would be done after the RPV had been placed in the shipping cask and after the annular space between the RPV and cask has been filled with grout. The grout and shipping cask will provide radiation shielding and will help to contain any radioactive debris generated by the sampling process. Further discussion of the preferred sampling method is provided in Appendix A.

Cost Estimate

The basis for the estimated cost to obtain trepanned samples from the SONGS-1 RPV is discussed in Appendix A. The total estimated cost for obtaining the desired materials is about $1.5 million. This estimate assumes obtaining good cooperation from the parties involved [SCE, the Electric Power Research Institute, Oak Ridge National Laboratory (ORNL), and the U.S. Nuclear Regulatory Commission (NRC)] and includes a modest contingency.

Summary and Recommendations

Sampling the SONGS-1 RPV and obtaining measurements of the through-thickness variation in the radiation-induced Charpy shift would provide much needed data to evaluate the predictions of current and proposed regulatory documents. Because of the long time required to obtain



(a)

(b)

Figure 1. Charpy shift data from the SONGS-1 surveillance program. SONGS-1 plate and correlation monitor material (CMM) data are compared with other CMM data and with current embrittlement correlations on (a) linear and (b) logarithmic scales.

Table 1. Options for Sampling SONGS-1 RPV				
LOCATION AND CONDITION	**ISSUES**	**PERMISSION REQUIRED**	**OTHER ISSUES**	**FEASIBILITY RANKING**
(a) from inside out **SONGS site, in-place within containment**	- access due to internals - SCE schedule	SCE and its subcontractors	- SCE plan to grout RPV full as soon as cavity and RPV drained	**4** **(most difficult engineering)**
(b) from outside in	- access between RPV and cavity wall - thermal insulation on RPV - SCE schedule	SCE and its subcontractors	- 5-week window between cavity/RPV draining and RPV lift - concurrent work to cut nozzles	**3**
SONGS site, after removal, before placing in shipping cask	- personnel exposure - cutting debris - SCE schedule	SCE and its subcontractors	- cavity-to-cask transfer time relatively short - sufficient clearance unlikely while RPV on jacks - not feasible while hanging from crane	**5** **(not feasible)**
SONGS site, inside shipping cask	- cutting debris - SCE schedule, 12/26/2002 ship date - cask integrity and shipping license	- SCE and its subcontractors - DOT on cask shipping license	- predrill threaded holes in cask for closure (grouting holes already planned) - RPV alignment in cask, particularly if predrilled - cask design nearly complete, about to be ordered - revision of DOT license submittal	**1** **(SCE schedule critical)**
Barnwell site, inside shipping cask	- cutting debris - cask integrity for burial - impact on operations due to 50k Curie limit	State of South Carolina and Barnwell contractor (Chem-Nuclear Systems/Duratek)	- RPV alignment in cask - location (i.e., before or after placement in burial trench)	**1** **(State permission critical)**

mechanical-property data at commercial RPV operating conditions, there is no good alternative to obtaining such data from a decommissioned reactor vessel. The use of the SONGS-1 RPV is an excellent opportunity because it contains material typical of that used in many plants operating in the United States and because it has achieved a very high neutron exposure.

In order to take advantage of either of the two preferred sampling options, work must be initiated quickly. In addition to the financial costs, a successful sampling project will require substantial support from the NRC in dealing with the logistical and political obstacles that are already known. SCE's decommissioning schedule leaves little time for operation at its site because it has a commitment to ship the RPV by rail during the last week of December 2002. Therefore, in order to sample the RPV at San Onofre, at least the following conditions must be met.

1. Adequate time must be available in the schedule after the RPV has been grouted into the shipping cask and before the fixed shipping date arrives.
2. Issues associated with restoring shipping-cask integrity after it has been drilled to obtain the trepans must be resolved. This is a critical-path item because it will involve some redesign of the shipping cask to meet U.S. Department of Transportation (DOT) requirements.
3. Agreement must be obtained with SCE on the logistical details for performing the sampling in a way that does not contaminate the SONGS site.

A similar set issues must be resolved in order to take the samples after the RPV container has arrived at the disposal site in Barnwell, South Carolina.

1. An exception from the state of South Carolina will be required for the Barnwell site to temporarily exceed its current limits for unburied activity.
2. Issues associated with restoring shipping-cask integrity for burial after it has been drilled to obtain the trepans must be resolved.
3. Agreement must be obtained with the Barnwell contractor (Chem-Nuclear Systems, a subsidiary of GTS Duratek) on the logistical details for performing the sampling in a way that does not contaminate the Barnwell site.

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[6] Timothy Clepper, personal communication, from the files of Southern California Edison.

[7] Charles Beil, personal communication, from archives of Bethlehem (Lukens) Steel.

[8] J. A. Wang, *Embrittlement Data Base, Version 1*, NUREG/CR-6506, ORNL/TM-13327, U.S. Nuclear Regulatory Commission, August 1997.

Appendix A

Cost Estimate for Obtaining Trepans from SONGS-1 RPV
(Prepared by MPR Associates, Alexandria, Va., in collaboration with the Oak Ridge National Laboratory Heavy Section Steel Irradiation Program staff)

Summary

This appendix provides the scope and cost estimates for removing 4- to 5-in.-diam through-wall samples from the San Onofre Nuclear Generating Station, Unit 1 (SONGS-1) reactor pressure vessel (RPV). The proposed project would remove six trepan samples, two each from very-low-flux, moderate-flux, and high-flux regions of the cylindrical section of the vessel wall. To minimize the impact on the plant decommissioning schedule, the samples would be removed from the vessel after it was placed in its shipping container and grouted. The sampling activities could be performed at the SONGS-1 site prior to shipment or after the package has been shipped to the Barnwell Repository in South Carolina.The samples from the vessel wall could be cut by specially designed mechanical trepanning tooling. The cost to perform this work is estimated to be $1.2 to $1.6 million.

Introduction

This appendix provides a conceptual study identifying the scope, schedule, and budgetary estimates associated with removal of through-wall core samples from the SONGS-1 reactor vessel. The sampling activities are assumed to occur after the vessel has been removed from the containment building and inserted in its shipping container and after the container and vessel have been filled with grout. The sampling is assumed to occur with the vessel and shipping container positioned horizontally in its shipping support structure, either before it leaves the San Onofre site or after it has reached the Barnwell repository, where it will be buried.

Thehe following tasks are included in the scope of this study:

- identification of the major tasks associated with the sampling project;
- conceptual engineering to identify potential cutting methods, shielding components, and sample transfer and shipping containers;
- estimation of the schedule for performing detailed engineering to define tooling and processes;
- estimation of schedule for site activities associated with sampling activities; and
- estimation of the cost associated with the engineering and site sampling activities.

San Onofre Unit 1 Vessel and Proposed Shipping Container

A schematic of the SONGS-1 reactor vessel surrounded by a shipping container is shown in Figure A-1. It is a low-alloy carbon steel reactor vessel that is 37 ft long, has an outer diameter of 13.5 ft, and has a wall thickness of 9.75 in. The inner surface of the vessel is clad with 5/32-in. (minimum thickness) of stainless steel. The total weight of the vessel, including the head and closure studs and nuts, is approximately 696,000 lb.

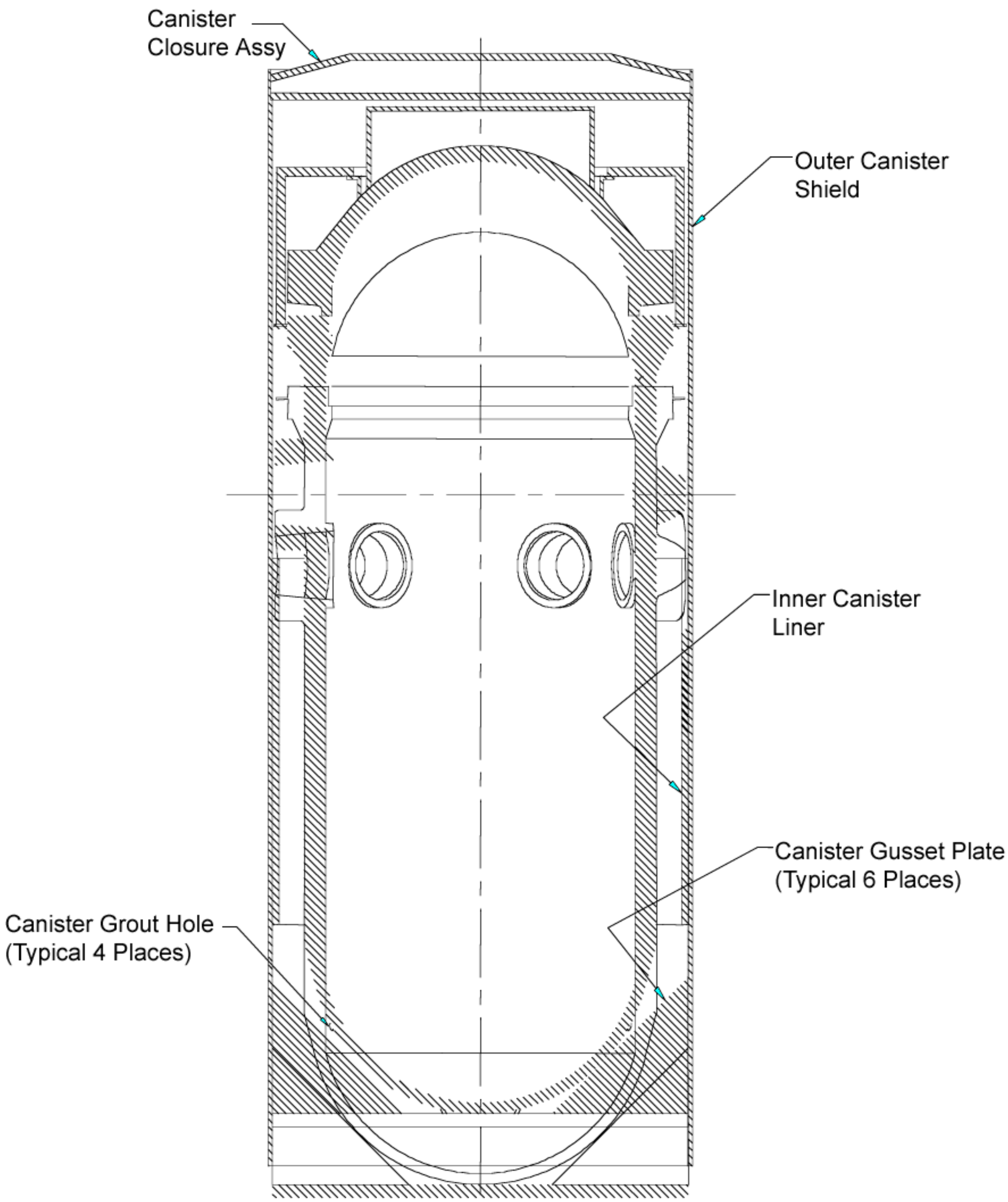

Figure A-1. SONGS-1 reactor vessel and shipping container.

The SONGS-1 plant was shut down in 1992 and is in the process of being decommissioned. As part of the decommissioning, some of the internals will be removed from the RPV before the vessel is removed from the reactor building. The RPV will be put into a shipping container and shipped by special rail car to the Barnwell repository for final burial.

The shipping container being designed for the RPV will meet the requirements for a U.S. Department of Transportation (DOT) Type 7A container. These requirements are published in 49 CFR 173 Subpart A and Subpart B, and in 49 CFR 173 paragraphs 410, 412, 461, 462 and 465. These regulations require that the container maintain containment and shielding for specific operating conditions, including a 1-ft drop and a decrease in ambient pressure to 3.6 psi (i.e., an internal pressure of 11.1 psi). Figure A-1 shows the current design concept for the shipping container, a section view of the shipping container as well as the vessel as it would be installed in the container. The RPV and the container will be filled with grout for stabilization. The shipping container concept involves use of rolled and welded 2-in.-thick plate to fabricate the basic container. In the cylindrical section of the container corresponding to the beltline region of the vessel, an additional 3-in.-thick rolled-plate section is included, which results in a 5-in.-thick wall. The outer diameter of the container will be 15.6 ft.

Proposed Scope of Sampling Activities

The proposed sampling would remove six trepan samples from the cylindrical portion of the RPV. Two trepan samples will be taken at three different elevations in the vessel, a high-flux region in the beltline weld, a medium-flux region below the beltline, and a very-low-flux region in the nozzle course weld that can be used to obtain an estimate of unradiated properties. The heats of plate material used to fabricate the vessel will be reviewed to determine whether sampling locations can be chosen such that all six trepans are from the same heat. The trepan samples will be 4 to 5 in. in diameter and 9.75 in. long. To minimize the impact on the SONGS-1 decommissioning schedule, the trepans may be taken either after the vessel is removed from the containment building and prior to shipment to the burial site at Barnwell or after the vessel has arrived at Barnwell.

Evaluation of Sampling Prior to Removing Vessel from Containment

Performing the sampling activities after the vessel has been installed in the shipping container offers several advantages over sampling while the vessel is in the containment. First, the sampling activities have less of an impact on the critical-path schedule for plant decommissioning. Second, removing the samples from the RPV with it in the container eliminates considerable difficulties and costs associated with removing samples from the vessel while it is still in containment. These difficulties are associated with underwater remote tooling if sampling is performed with water in the vessel or with shielding and with personnel access if the vessel is drained. In addition, if cutting were performed from the exterior of the vessel with it still in the containment, there would be significant access and radiological issues. Accordingly, the preferred option is to perform sampling activities after the vessel has been removed from containment and after it has been is installed in the shipping container and grouted.

Scope and Estimated Costs of Sampling Tasks

The SONGS-1 RPV sampling project will involve a significant engineering effort to define sampling processes and to design tooling for cutting and handling the trepans. In addition, regardless of whether the sampling is done at the SONGS or at Barnwell, engineering tasks associated with restoring the structural integrity of the shipping container after sampling is complete will be required. To define the scope of the sampling project, the specific engineering tasks involved with preparing for sampling are identified as follows:

1. definition of sampling scope and project management,
2. sample-removal tooling development,
3. design of shipping-container modifications,
4. resolution of regulatory issues, and
5. performance of sampling activities.

Each of these activities is discussed in detail to identify the specific scope of work and to provide an estimated cost.

Definition of sampling scope and project management
Significant engineering effort is required to evaluate the vessel is as-built condition, to choose the specific sampling sites, to define the scope of the sampling project, and to provide project management and oversight. The estimated cost for tasks associated with definition of the project scope and management of the project is $50,000.

Sample-removal tooling development
One of the major activities associated with the sampling effort is the development of the trepan-removal tooling. This includes the tooling to cut the trepan from the vessel, shielded canisters to house and ship the trepans, and tooling for transfer of the trepans into the container. This major task involves all aspects of tooling development, including

- tooling conceptual design,
- proof-of-principle testing,
- tooling prototype development,
- tooling qualification and cutting parameter definition,
- Primary and backup tooling fabrication/procurement, and
- Tooling operation procedure development.

Candidate cutting processes include mechanical, abrasive water jet, and electrical-discharge machining (EDM). Abrasive water jet offers the advantage of quick, accurate cutting without any thermal degradation of the samples but was eliminated because it would involve a large amount of water and abrasive. The resultant radiological and waste containment and disposal issues and the potential impact on the grout in the shipping container were judged to be too significant for abrasive water jet to be considered viable. EDM offers the advantage of low tooling reaction loads but was also considered not viable because of the requirement of a dielectric fluid between the workpiece and the cutting electrode and because of the very slow cutting times. The preferred cutting method was determined to be mechanical cutting with a trepanning tool.

Research of the existing industrial trepanning technology revealed that, although common in machine shop environments, there is no commercially available trepan tooling for cutting samples of the diameter and depth required. Contacts with vendors specializing in trepan tooling and processes indicated that performing the desired cutting operations would require significant tooling development to adapt a fairly large (50 to 100-hp) shop horizontal boring machine for field use. Major design challenges include making the tool stiff enough to resist vibration and chatter and maintaining the precise alignment of the tool needed to ensure that bearings and cutting tools do not wear out before completion of the cut. Furthermore, a stiff and sturdy method for attaching the tool to the vessel would have to be engineered. The vendors also indicated that significant development and experimentation would be required to define the right set of cutting parameters to produce the length and shape of chip that can be flushed from a deep hole.

In addition to developmental work to engineer the tooling, engineering would be associated with tasks such as tooling qualification, personnel training, and procedure development. Given the complexity of the tooling development, cost estimates for these tasks range from $400,000 to $600,000.

Design of shipping-container modifications

Modifications to the DOT Type 7A container to be used to ship the RPV to the Barnwell site must be designed and implemented to allow removal of the samples from the vessel. Specifically, access ports through the shipping container wall will be needed to allow access of the tooling to the vessel wall. The access ports must be designed such that DOT Type 7A shipping-container requirements are satisfied, both before the ports are opened and after they are closed. The requirement that the shipping container be in compliance with the DOT regulations after sample removal applies whether the samples are taken at the SONGS-1 site or at Barnwell (based on discussions with Barnwell personnel).

The sample ports must be approximately 6 to 8 in. in diameter to allow access for cutting equipment that is capable of producing a 4- to 5-in. trepan sample. Engineering evaluations of the sample ports would be needed to verify that the requirements of 49 CFR Part 173 are met during shipping and after completion of sampling activities. The ports would need to meet the basic design requirements that they are not readily breakable and, when intact, they show evidence that the package has not been opened. In addition, evaluations would need to be performed to demonstrate that the ports remain sealed during the required package design conditions.

The most significant of the design conditions are the reduction of ambient pressure to 3.6 psi (i.e., internal pressure of 11.1 psi) and a 1-ft drop of the package onto a flat horizontal surface. Rough calculations using ASME Code equations for minimum required wall thickness and required area of reinforcement for openings indicate that the ports would be acceptable for the 11.1 psi internal pressure condition. To determine whether the ports are acceptable for the 1-ft drop, the features of the port would have to be incorporated into and addressed in the evaluations that were performed for the package for this design condition. Given the large size and weight of the package, the evaluations of the adequacy of the container for the 1-ft drop were expected to involve finite-element analysis. Additional evaluations to address the adequacy of the sampling ports may require local, elastic-plastic finite-element analysis of the container regions that include the sampling ports.

The costs associated with engineering the modifications to the shipping container to include sampling ports is estimated to be on the order of $75,000 to $100,000.

Resolution of regulatory issues

The vessel-sampling activities can be performed at the SONGS-1 site after removal of the loaded shipping cask from the containment vessel and prior to shipping or at Barnwell after shipping and prior to burial. There are several trade-offs associated with each of these options.

Duratek personnel at Barnwell indicated that there are problems with performing the sampling activities at the burial site. First, the sampling activities cannot be performed at the burial site because the burial site is not licensed for any processes or sampling of containers. Instead, the sampling activities would have to be performed at their consolidation facility adjacent to the burial site. Therefore, the package would be shipped from SONGS-1 to the Barnwell consolidation facility for sampling. After sampling activities are completed and the container is restored to meet DOT shipping requirements, the package would be transferred to the burial facility.

Activities involving containers (such as sampling) are typically performed at this consolidation facility. However, these activities are performed within containment structures to ensure that any radioactive material that exits the package is contained. Unfortunately, there are no containment structures within the consolidation facility large enough for an RPV. An exemption could be requested from the state of South Carolina, which regulates the Barnwell Repository. However, the Duratek contact noted that obtaining such an exemption would be difficult. He cited the transfer of responsibility for the Barnwell site from the South Carolina Department of Health and Environmental Control, which he characterized as a regulatory organization, to the South Carolina Budget and Control Board, which he characterized as a political organization. The Duratek contact stressed that, for vessel-sampling activities to be performed at Barnwell, a significant amount of effort would be needed to address the associated regulatory and site activities.

Southern California Edison's (SCE's) preference is to avoid any sampling activities performed at the SONGS site prior to shipping because of the potential for impact on decommissioning activities. If sampling activities are to be performed at SONGS-1, significant planning and coordination will be required to assure SCE that there will be no impact on the decommissioning schedules. Performing the sampling activities at SONGS-1 offers an advantage in that there will already be craft and health physics personnel on site to support the work.

Regardless of where sampling activities are performed, engineering will be required to ensure that any radioactive material that exits the shipping container will be contained when it is opened for sampling. Estimated costs to address material containment issues, as well as site support from Barnwell or SONGS-1, range from $150,000 to $200,000.

Performance of sampling activities
The sampling activities that would be performed on site include the following steps:

- mobilization of the sampling personnel and equipment to the site,
- setup of temporary shielding and containment,
- opening of sampling ports and removal of grout between the vessel head and container inner diameter,
- setup of cutting equipment,
- cutting of trepan samples,
- removal of samples from the vessel and packaging of the samples for shipping,
- remediation of the cavity in the vessel and container,
- reinstallation and rewelding of the sampling ports, and
- demobilization of the personnel and equipment.

The sampling team is estimated to comprise approximately 25 personnel with approximately half on day shift and half on night shift. Based on an estimated time to cut and handle each sample of 1.5 to 2 days, the sampling activities would take 10 to 15 days. Assuming that the average cost for each team members is $50/hour, the total personnel cost for sampling operations ranges from $150,000 to $225,000. Assuming that the total mobilization and demobilization costs range from $50,000 to $75,000, the total cost for deployment of the sampling team and equipment to the site is approximately $200,000 to $300,000.

Total Estimated Cost for Vessel-Sampling Project

The total estimated cost of the project to obtain samples from the SONGS-1 RPV based on the above analysis is on the order of $1 to 1.3 million. Given the cursory nature of the estimates generated in this appendix, a contingency factor of 15 to 20% should be added to the estimates to generate a more realistic cost. Application of this factor results in a cost estimate of $1.2 to 1.6 million.

Additional Sources of Cost Information

Additional cost information for the sampling project was obtained from two sources. The first source was Framatome Advanced Nuclear Power and the second was the Russian consortium MOHT.

Framatome was contacted to obtain information regarding abrasive water jet and EDM capabilities. In the course of the discussion, the Framatome contact indicated that Framatome had provided a cost estimate to an industry group to remove through-wall samples from the Maine Yankee reactor vessel. Like our proposed approach, Framatome proposed to cut the samples with a mechanical trepanning tool after the vessel had been inserted into the shipping container and grouted. Framatome has an existing mechanical trepanning tool used to perform reactor vessel maintenance work that Framatome staff felt could be adapted to perform the vessel sample cutting. Framatome staff estimated the cost to perform the Maine Yankee vessel sampling to be between $1 and $1.5 million. They estimate that the cost would be closer to $2 million today.

The Russian consortium MOHT has provided services both in Russia and in France for removing through-wall bore samples from irradiated and decommissioned commercial nuclear power plant RPVs. It utilizes a shielded cabin that is lowered into an empty reactor vessel. The shielded cabin is manned, and the trepan samples are obtained with special tools. This consortium has the equipment and personnel capable of providing similar services for the SONGS-1 site. MOHT staff estimate as cost of about $3.5 million for this work. They indicated that a similar task performed for the Electricite de France was competitively bid and that their price was substantially lower than the two alternate bids received.

A brief review of access and laydown space within the SONGS containment indicated that bringing such a shielded cabin into the containment and assembling it within the containment would pose a significant challenge.

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