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F. G. Burford
Acting Director
Nuclear Safety & Licensing

CNRO-2005-00017

March 18, 2005

U. S. Nuclear Regulatory Commission
Attn.: Document Control Desk
Washington, DC 20555-0001

SUBJECT: Supplemental Information for Request for Alternative ANO2-R&R-003 Proposed Alternative to ASME Requirements for Weld Repairs

Arkansas Nuclear One, Unit 2	Waterford Steam Electric Station, Unit 3
Docket No. 50-368	Docket No. 50-382
License No. NPF-6	License No. NPF-38

REFERENCES:

1. Entergy Operations, Inc. letter to the NRC, Request for Alternative ANO2-R&R-003 - Proposed Alternative to ASME Requirements for Weld Repairs, dated March 16, 2005

2. Entergy Operations, Inc. letter to the NRC, Request for Alternative W3-R&R-003 - Proposed Alternative to ASME Requirements for Weld Repairs, dated January 31, 2005

Dear Sir or Madam:

Pursuant to 10 CFR 50.55a(a)(3)(i), Entergy Operations, Inc. (Entergy) proposed an alternative to the temper bead welding requirements of ASME Section XI IWA-4500 and IWA-4530. As documented in Request for Alternative ANO2-R&R-003 (see Reference 1), Entergy proposed to perform an ambient temperature temper bead welding repair on one pressurizer heater sleeve at Arkansas Nuclear One, Unit 2 (ANO-2). In that submittal, Entergy committed to provide a copy of Welding Services, Inc. bases document, *Cooling Transients for Mid-Wall Weld Repair*, to the NRC staff. The bases document, including a supporting memo and calculation from Structural Integrity Associates, Inc., is enclosed.

In addition, Entergy submitted an equivalent request for Waterford Steam Electric Station, Unit 3 via Reference 2, which is currently being reviewed by the staff. This supporting documentation is applicable to both the ANO-2 and Waterford 3 requests for alternative.

A047

Entergy requests NRC approval of ANO2-R&R-003 on an emergency schedule in order to support activities being performed during the ANO-2 refueling outage, 2R17, which commenced on March 9, 2005. This letter does not contain any new commitments. Should you have any questions regarding this submittal, please contact Bill Brice at (601) 368-5076.

Sincerely,

FGB/
Enclosure: Cooling Transients for Mid-Wall Weld Repair

cc: Mr. W. A. Eaton (ECH)
Mr. J. S. Forbes (ANO)
Mr. J. E. Venable, Jr. (W3)

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ENCLOSURE

CNRO-2005-00017

Cooling Transients for Mid-Wall Weld Repair

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March 17, 2005

Cooling Transients for Mid-Wall Weld Repair

By Luis D. Yepez (WSI Welding Quality Manager)
Richard E. Smith (WSI Technical Specialist)

PURPOSE: The purpose of this evaluation is to establish a minimum conservative hold time between beads for the mid-wall repair without taking interpass temperature measurements. A holding time was evaluated based upon experimentally determined cooling transients then backed by heat transfer analysis.

CONCLUSION: It was determined that a 5-minute (300 second) hold time between weld beads provides a very conservative wait to assure that a 350^0F maximum interpass temperature will never be exceeded.

APPROACH: The demonstration and validation that a 5-minute pause between weld passes of the pressurizer heater sleeve mid-wall weld repair will be more than sufficient to ensure that the maximum interpass temperature of 350^0F will not be exceeded was approached by a combination of experiment and thermal heat transfer analysis. The experiment was conducted on a WSI mockup facility designed to evaluate parameters for the mid-wall weld repair. The mock-up design featured a water cooling chamber surrounding a cylindrical weld test sample holder – a design considered conservative with respect to the pressurizer head. The purpose of the water jacket was to introduce additional cooling to the weld test samples (shown in Figure 1) such that effects related to rapid cooling from the heavy section ferritic pressurizer head (approximately 4 inches thick) could be investigated during welding. It was acknowledged that the simulated cooling would be less effective than would be the case for the actual head, but for the purpose of the interpass temperature measurement, the simulation represented a conservative approach. The welding experiment is described below. In parallel to this experiment, a heat transfer analysis was conducted to demonstrate that the experiment was in-fact conservative. The analysis assumed appropriate heat transfer coefficients for the mock-up assembly that appropriately modeled the measured temperature-time relationships. Next the mock-up heat sink and heat transfer coefficients were removed analytically and replaced by an assumed model that simulated the pressurizer head. By comparing these results, it was possible to demonstrate the conservative nature of the heat removal capacity of the mockup.

TECHNICAL BACKGROUND: The mid-wall weld repair approach utilizes the "Ambient Temperature Temperbead Welding Technique", as addressed on ASME Code Case N-638. Welding variables are addressed on WSI's Welding Procedure Specification (WPS) No: 03-43-

T-802, Rev. 1. The Code Case mandates a maximum interpass[1] temperature of 350°F for all beads of all layers. This requirement is identified on the referenced WPS. During field implementation of mid-wall weld repair it is the intention of WSI to eliminate the need to take interpass temperature measurements because of the difficulty related to geometrical restrictions, and because of time constraints and radiological concerns. A 5 minute hold time has been suggested between beads with no interpass temperature monitoring. This approach is supported by a practical demonstration on a weld sample having dimensions appropriately scaled to field conditions. The transients measured are considered conservative since the true heat sink associated with the heavy walled pressurizer head is massive. Confirmation for this conclusion is provided in the attached heat transfer analysis.

EXPERIMENTAL ASSEMBLY: The array used to determine the cooling transients for mid-wall weld repair was similar to the assemblies used during R&D phase of the project. This consists of an approximately 1.66" OD alloy 690 sleeve having a wall thickness of 0.180" inserted into a piece of P1 Group 1 carbon steel having approximate dimensions of 1.72" ID, 4.00" OD (identified as the "bullet"). The bullet assembly is inserted into a circulating water cooled mockup cavity and is coupled to the wall of the water jacket cavity by packing the annulus between the bullet and the cavity wall with fine iron shot. This step is taken to simulate the heat sink attributed to the pressurizer head. The heat sink achieved in the actual pressurizer head will be greater and thus the measurements taken are considered to be conservative.

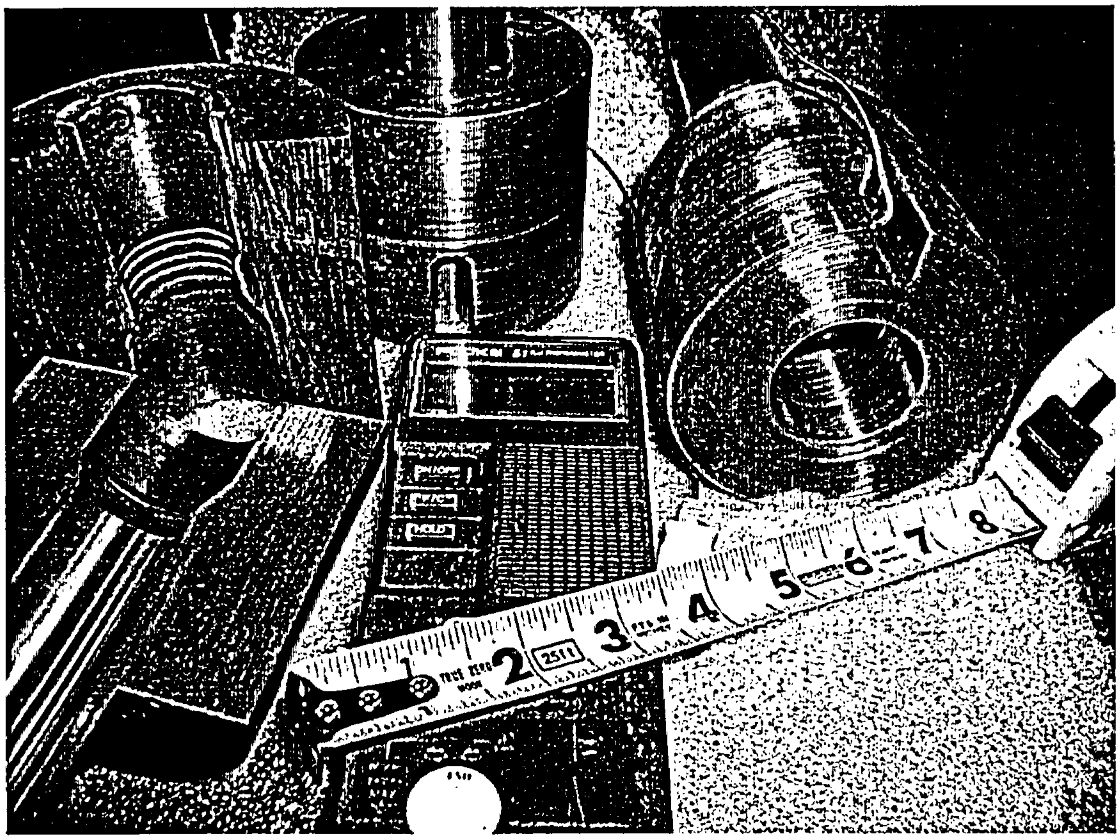
A notch was machined on the outer surface of the bullet to facilitate installation of a thermocouple opposite to the weld area (see Figure 1). The remaining thickness on the area where the thermocouple was attached was approximately 0.5". The thermocouple was connected to a digital thermometer Fluke 51k/j serial number 5660084 which was calibrated in accordance with WSI's Nuclear Quality Assurance Program. Temperature readings were taken at 15 seconds intervals after completing the weld pass being measured and recorded on a spread sheet.

The weld was fabricated according to parameters identical to that used for the mid-wall weld repair. Alloy 52M[2] SFA ER NiCrFe-7A was used as the bare wire filler material. The third bead of each layer was selected for the thermal transient measurements. The selection of this bead represented a location approximately mid-position on the weld, and was considered appropriate for the experimental testing.

[1] For the purposes of this paper, interpass temperature is defined as the maximum temperature at the area where weld metal was previously deposited, immediately before the next bead is started.

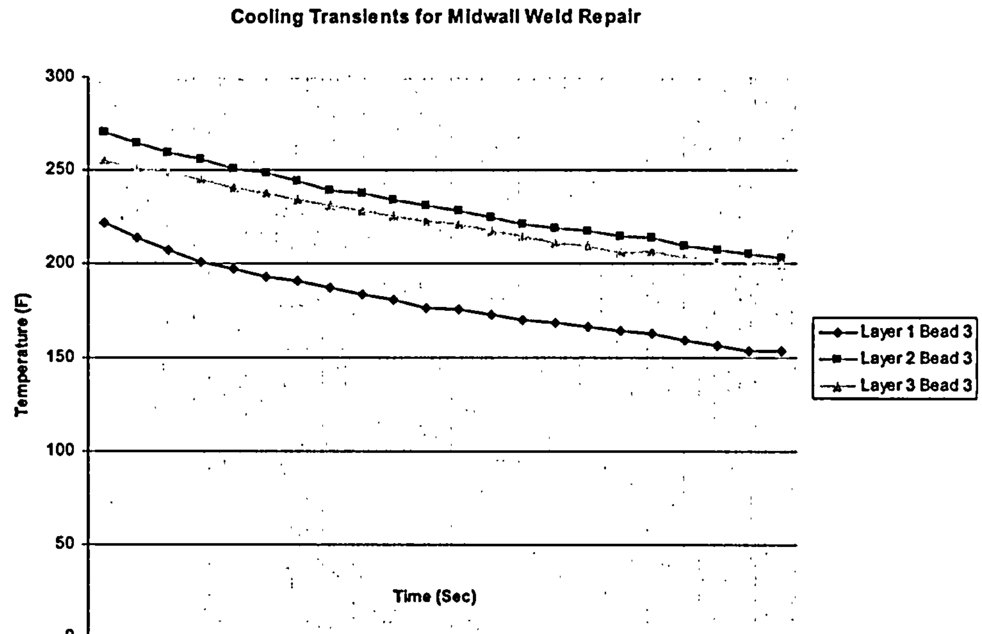
[2] Reference Code Case 2142-2

Figure 1 – Experimental Assembly



RESULTS: The results of the measurements for the cooling transients are summarized in Figure 2. The maximum temperature recorded was 270.5°F on the 3rd bead of the second layer. The maximum temperatures on the 3rd beads of the 1st and 3rd layers were 221.6°F and 255.1°F respectively. 5 minutes later, the recorded temperatures had dropped to the 150°F to 200°F range. These values are well below the maximum interpass temperature of 350°F required per Code. These results are consistent with the values observed during the R&D phase of the project and clearly demonstrate that interbead temperature measurements are unnecessary. It is noted that the rates of cooling (slopes of the plotted curves) are approximately the same for each layer, but the maximum temperatures for each initiation point are slightly different. This is likely a phenomenon based upon slight overall heating of the mockup assembly. The actual pressurizer will not tend to heat up due to the much larger mass of the thick walled head. Therefore the starting points are not expected to increase very much in the actual head. The rate of cooling is approximately 0.25 deg F/sec for each transient.

Figure 2 – Results of Temperature measurements



	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330
Layer 1 Bead 3	222	214	207	201	197	193	191	187	183	181	177	175	173	170	169	166	164	163	159	156	153	153
Layer 2 Bead 3	271	265	259	256	251	248	244	239	238	234	232	228	225	221	219	218	215	214	210	207	205	203
Layer 3 Bead 3	255	251	249	245	241	238	234	231	229	225	223	221	218	215	211	210	206	207	203	202	201	199

(Recorded Temperatures)

ANALYSIS: The heat transfer analysis was conducted by Mr. Art Deardorf of Structural Integrity Associates. This analysis modeled the experimental setup for 6 weld passes, by introducing a representative heat input setup and estimating the heat transfer across the experimental materials. These temperature transients were compared to the experimental measurements described above. Next the heat transfer surfaces were removed and replaced by a 24 inch length of ferritic material similar to the thickness of the pressurizer head. The same temperature transients were repeated and the results compared to similar results produced for the mock-up facility (Figure 1 of Attachment 1). Finally, the radial temperature distribution was plotted for the end of welding and the end of cooling for the 6th weld pass for both the experimental set-up and for the simulated pressurizer head. These results are shown in Figure 2 of Attachment 1). These results show that the welding location can never achieve temperatures even approaching the 350^{0}F maximum interpass temperature. Therefore the 5 minute hold time is very conservative. The letter report provided by Structural Integrity for the heat transfer analysis is included as Attachment 1.

CONCLUSION: The maximum temperature recorded during the experimental activity was 270°F and that temperature decayed at approximately 0.25^{0}F/sec. Therefore the temperature of the weld volume 5 minutes after the weld pass was completed was approximately 200°F.[3]. This value is well below the 350°F maximum interpass temperature prescribed by the WPS.

Second, the heat transfer analysis showed that the heat sink provided by the actual head is much greater than that simulated in the mock-up facility. In fact the type and size of the welds applied to the mid-wall are incapable of heating the actual head to temperatures as high as the interpass maximum.

For these reasons the 5 minute hold time between beads, recommended by WSI, is considered a very conservative approach for controlling interpass temperature in the mid-wall repair. Therefore temperature monitoring is unnecessary and the requirement for limiting interpass temperatures below 350^{0}F can be controlled effectively by procedure (i.e. A minimum 5-minute hold between individual beads).

[3] The temperature may decay more rapidly in the field due to the greater mass of the heat sink offered by the actual component (pressurizer). In addition, the starting temperature will not tend to increase as was the case in the experimental setup.

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March 17, 2005
RAM-05-015
SIR-05-081, Rev. 2

Mr. Jim Puzan
Welding Services Inc.
2225 Skyland Court
Norcross, GA 30071

Subject: Evaluation of Pressurizer Wall Temperature Response During Mid-Wall Repair

Reference: "Cooling Transients for Mid-Wall Repair," Welding Services Inc., February 1, 2005

Dear Jim:

Per discussions with Dr. Richard Smith, Structural Integrity Associates (SI) has performed analysis to quantify the effects of the pressurizer bottom head as a heat sink as compared to the qualification test facility described in the reference above. From this evaluation, it is concluded that the interpass temperature will be much less than the ASME Code 350°F limit since the pressurizer wall will provide much more cooling than that which occurred during the qualification test.

APPROACH

During the WSI mid-wall repair qualification activities, testing was performed that showed there would be no need to monitor the interpass temperature during the mid-wall repair. In the qualification testing, the pressurizer wall was simulated by a 4-inch long (simulating the pressurizer wall thickness) by 4-inch diameter cylinder with a 1.72-inch diameter hole, in which the welding to the end of the heater sleeve was performed. This cylinder was surrounded by a thin annulus of iron shot to assure heat conduction to a surrounding source of cooling water. Data taken during the evaluation showed that the maximum temperature of the cylinder (approximately 0.5 inches from the inner surface) was about 271°F 15 seconds after the start of a cooling period and reached about 207°F after cooling for 300 seconds.

To compare the test facility temperature response to that expected in the actual pressurizer vessel wall, two one-dimensional heat transfer analyses were conducted using the SI computer program PIPE-TS2. In both cases, a series of six weld bead applications were analyzed, consisting of 108 seconds of welding (based on an assumed 3-inch/minute travel speed – bead deposit time) followed by a 300 second cooling time, with each cooling period immediately followed by another period of welding.

1. For the first case, the test fixture was modeled as a 4-inch OD by 1.72-inch ID carbon steel cylinder. A heat flux was applied to the inside surface of the cylinder, such that after 6 consecutive weld/cooling sequences, the wall temperature at the thermocouple location would reach the maximum of 271°F (at 15 seconds after termination of welding), and then would cool to about 207°F (300 seconds after termination of welding). This was accomplished by determining a value of inside heat flux (to simulate the welding) and external heat transfer coefficient (to simulate the iron shot and water heat transfer coefficient) that would duplicate the data. The cooling water jacket was assumed to remain at a constant temperature of 120°F.

2. For the second case, the same heat flux was applied, but the cylinder was increased to 24 inches outside radius to simulate the extent of the pressurizer vessel wall remote from the repair location. This is conservative since no credit is taken for natural convection from the pressurizer vessel inside or outsides surfaces. In addition, the material properties were changed since the pressurizer shell is SA-533, Grade B, Class 1, and because the remote penetration reduces the effective thermal conductivity and heat capacity of the shell.

In both cases, the initial temperature was taken as 120°F. The model employed a cylindrical geometry, taking credit for the increasing metal volume and heat transfer capability with increasing radius away from the sleeve penetration.

RESULTS

The attached calculation provides a more complete description and shows the results. By comparing the temperature transient responses of the two cases, it is shown that the pressurizer shell is a very effective heat sink as compared to that used in the qualification test facility. This is further demonstrated by examining the radial temperature distribution for the actual pressurizer case that shows very little temperature response in the shell remote from the repair location.

CONCLUSIONS

The heat sink capability of the pressurizer wall far exceeds that used in the WSI weld qualification testing. Due to the small diameter of the hole in which the welding is to take place, and the 300 second pause between deposition of the individual weld passes, the temperature of the pressurizer shell prior to the next weld should not exceed about 150°F. This is much less than the 200°F claimed in the WSI evaluation, and is much lower than the ASME Code-required 350°F maximum interpass temperature.

Please call if you need further clarification.

Prepared by:

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Reviewed by

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Approved by

Richard A. Mattson, P.E.
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ml
Attachment (WSES-10Q-319)
cc: R. E. Smith
WSES-10Q-404

Structural Integrity Associates, Inc.	CALCULATION PACKAGE	File No.: WSES-10Q-319 Project No.: WSES-10Q

PROJECT NAME: Waterford-3 Pressurizer Small Bore Nozzle Repairs

Contract No.: 31181

CLIENT: Entergy Operations, Inc.	PLANT: ANO Unit 2 and Waterford Unit 3

CALCULATION TITLE: Heat Transfer Evaluation of Mid-Wall Repair Qualification Test

Document Revision	Affected Pages	Revision Description	Project Mgr. Approval Signature & Date	Preparer(s) & Checker(s) Signatures & Date
0	1-9	Original Issue	3/17/05	3/17/05 3/17/05

SI Form F2001R2a

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1 INTRODUCTION

Welding Services, Inc. (WSI) performed testing to establish a conservative hold time between weld beads for the mid-wall pressurizer heater sleeve repair that would justify not recording interpass temperature measurements [1]. It was determined that a 5-minute hold time between weld beads would conservatively assure that the Code-required 350°F maximum interpass temperature would not be exceeded.

The objective of this calculation is to show that the qualification test was conservative, since there were some aspects of the test that did not simulate the actual pressurizer bottom head configuration. Specifically, a water-filled cooling jacket was used to maintain temperature of the metal being welded. In the pressurizer, there is a continuous low-alloy steel shell which acts as the heat sink.

The, the purpose of this calculation will be to establish that the qualification test was conservative relative to establishing that the 350°F maximum interpass temperature would not be exceeded. As such, the main emphasis is on showing that the pressurizer shell provides much more heat sink and that it provides a much more effective heat transfer path to provide more cooling, as compared to the water-jacketed test configuration.

2 TECHNICAL APPROACH

A one-dimensional heat transfer analysis will be conducted for both the test conditions and for the actual pressurizer bottom head geometry. Since the question at hand is related to how the heat sink in the test facility compares to the heat sink afforded by the pressurizer bottom head, the one-dimensional analysis will be sufficient to make this comparison.

In the actual mid-wall repair welding process the welding occurs at the about the center of the pressurizer wall, taking a finite time to deposit the weld metal around the circumference. Then, there is a hold time to allow the heat to be conducted into the adjacent pressurizer wall. This was simulated in the WSI qualification testing and temperature measurements were taken to measure the response.

For the one dimensional analysis, a heat flux will be applied to the model to simulate the welding on the inside surface of the test facility and to match those determined in the qualification test. Similarly, a heat transfer coefficient will be determined such that the measured cooling will be properly simulated. This approach is necessary since the effectively of the water jacket can not be exactly determined. By iteratively determining these two parameters, the test facility response can be simulated.

Then, using the same heat flux, an analysis will be conducted with the cooling jacket replaced by pressurizer shell materials and a more representative model of the mass and extent of the pressurizer shell heat sink.

In the comparison, the effects of the difference between the test article material and the actual pressurizer bottom head materials and geometry will be addressed.

3 ASSUMPTIONS / DESIGN INPUTS

The test is described in the letter report by WSI [1]. The testing facility consisted of carbon steel (P1 Group 1 material) cylinder that was 1.72 inches ID by 4 inches OD to simulate the pressurizer shell. This cylinder was surrounded by a cooling water jacket and fine iron shot was packed between the cylinder and the water jacket.

Per communication with Mr. Dick Smith of SI, who is assisting WSI, the length of the cylinder was 4 inches (to simulate the pressurizer shell), and the welding speed was 3 inches per minute (or $\pi \cdot 1.72 \cdot 60/3 =$ 108 seconds per pass)[5]

A thermocouple was mounted in a groove machined into the outside of the cylinder to measure a temperature at about 0.5 inches from the inside surface of the cylinder. Temperatures were measured at 15-second intervals following termination of welding. For the maximum temperatures recorded, the temperature was 271°F at 15 seconds and 207°F at 300 seconds [1].

It will be assumed that the ambient temperature (e.g. of the cooling water jacket and the initial pressurizer shell) are at 120°F for the comparison.

The pressurizer bottom head is made of SA-533 Grade B Class 1 [2]. The thermal properties at 100°F are given in that reference and are:

- Thermal conductivity, k = 5.23E-4 Btu/sec-in-°F (22.6 Btu/hr-ft-°F)
- Density, $\rho = 0.283$ lb/in^3
- Specific heat, $C_p = 0.108$ Btu/lb-°F
    - Thus, the density times specific heat for the pressurizer shell material is 52.81 Btu/ft^3-°F

The test article material will be taken as low-carbon steel with properties at 200°F taken from the Code [3]

- Thermal conductivity, k = 33.6 Btu/hr-ft-°F
- Thermal diffusivity, $\alpha = 0.613$ ft^2/hr
    - Using the relationship $\rho C_p = k/\alpha$, density times specific heat = 54.8 Btu/ft^3-°F

The pressurizer bottom heat is filled with heater sleeves that may be at an angle. The sleeves are arranged in a 5.375-inch center-to-center square pattern [2]. It will be conservatively assumed that there is a 1.72 inch diameter hole though each corner of the pattern (representing a quarter of the total hole area at the corner of each 5.375-inch square array). It will also be assume that the sleeve hole is at 45 degrees inclined from the perpendicular, forming an elliptical opening at the surface of the pressurizer bottom head. Thus, the metal volume is reduced by the following factor.

Factor = 1 – Hole Area/Total Area

$$= 1 - [\pi (1.72)^2/4 \times 1.414/5.375^2]$$

$$= 0.8863$$

This factor will be applied to reduce the material density in the region beyond a 2-inch radius for a model that includes the pressurizer bottom head material, and will similarly be applied to reduce the thermal conductivity. This factor is conservative in reducing the heat sink capacity of the pressurizer material around where the weld is being conducted. Thus, modifying the thermal properties of the pressurizer bottom head gives:

- Thermal conductivity, k = 22.6 Btu/hr-ft-°F $\times$ 0.8863 = 20.03 Btu/hr-ft-°F
- Density times specific heat, ρCp = 52.81 Btu/ft^3-°F $\times$ 0.8863 = 46.8 Btu/ft^3-°F

Since a one-dimensional radial heat transfer calculation (using radial geometry) is being conducted, there is no consideration of heat lost from the inside or outside surfaces of the pressurizer shell. There is also no consideration of heat loss from the inside of the cylinder. This is conservative in that it will result in the maximum heatup of the pressurizer shell.

The model will only consider a total radial dimension (along the pressurizer shell) for purposes of evaluating the heat sink capacity. In addition, the radial dimension at 24 inches will be assumed to be insulated (adiabatic), maximizing any heat retained in the pressurizer shell region.

4 CALCULATIONS

To perform this analysis, the SI computer program PIPE-TS2 is used [4]. This finite-difference computer program solves for the temperature and stress response of an infinitely long cylinder with no circumferential temperature variation (variation only in the radial direction).

The first step of the analysis is to make several runs to experimentally determine the internal heat flux and the external heat transfer coefficient that will simulate the response observed in the WSI qualification testing. The analysis is conducted for six weld bead passes at which time there is only about 2 degrees difference in final temperature between the 5th and the 6th passes.

The internal heat flux, applied only during 108 seconds of welding, is applied by assuming an internal temperature of 100,000°F and resulted in an effective heat transfer coefficient of 0.2575 Btu/hr-ft^2-°F or a heat flux (Q") of approximately 25,700 Btu/hr-ft^2. Similarly, the external heat transfer coefficient to simulate the testing simultaneously with the above heat flux was 25.45 Btu/hr-ft^2-°F. This combination resulted in a temperature of 270.8°F at 15 seconds after completion of the 6th weld pass at 2148 seconds and 207.4°F at 300 seconds after end of welding (for a depth into the wall of 0.49 inches from the ID surface), comparing very closely to the measurements by WSI.

The analysis was then re-run with the same heat flux but with the external boundary conditions replaced by the pressurizer shell material with modified properties. For this analysis, the material next to the weld surface was also changed to SA-533 which has a lower thermal conductivity than the carbon steel.

The two models are shown in Figures 1 and 2.

5 RESULTS OF ANALYSIS

Figure 3 shows the simulated response of the inside surface of the pressurizer heater sleeve during 6 weld passes for both the test simulation and for the expected welding in the pressurizer. This figure shows that the pressurizer heat sink is significantly better than the test facility in assuring that the temperature remains low.

Figure 4 shows the radial temperature response for both cases. The temperature of the pressurizer shell remains very low, and there is significantly less thermal resistance between the area of the welding and the remote shell than was simulated in the test facility.

6 CONCLUSIONS AND DISCUSSIONS

This analysis shows that the WSI testing was very conservative in that it provided significantly less of a heat sink than will be provided by the actual pressurizer shell.

The temperature between weld passes will remain significantly below the Code-required 350°F limit when there is a 5-minute hold time between weld passes.

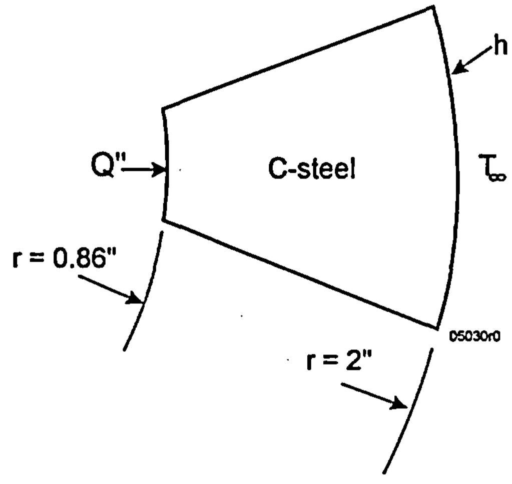

Figure 1: Depiction of Thermal Model to Simulate Qualification Test

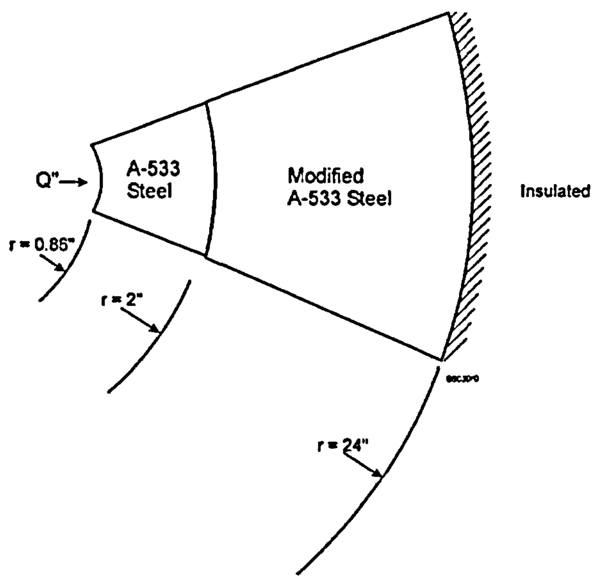

Figure 2: Depiction of Thermal Model to Evaluate Welding in Pressurizer Shell

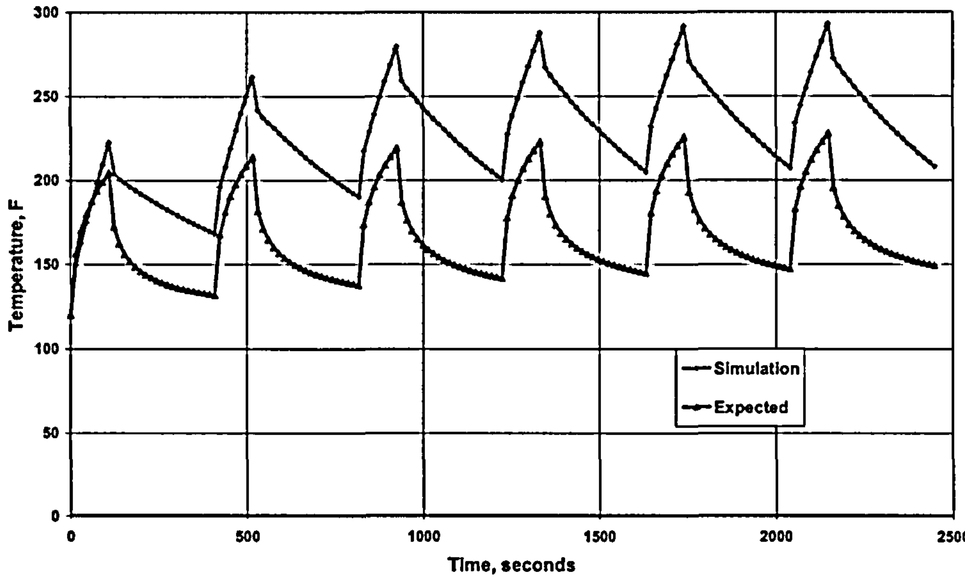

Figure 3: Time-Temperature Response of Inside Surface for Test Simulation and Actual Pressurizer

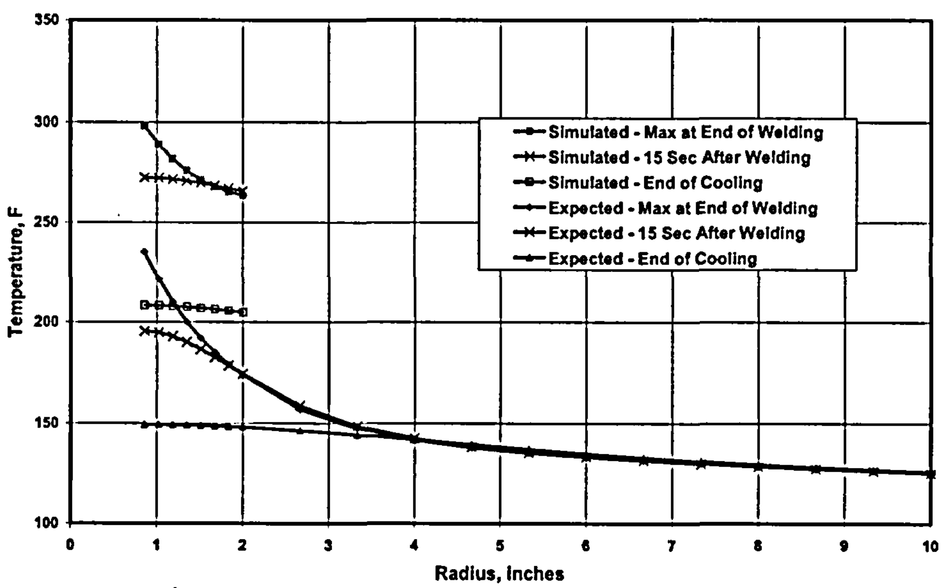

Figure 4: Radial Temperature Comparison for Test Simulation and Actual Pressurizer

7 REFERENCES

1. Yepez, L. D., and Smith, R. E, "Cooling Transients for Mid-Wall Weld Repair," Welding Services Evaluation, Dated March 15, 2005 (SI File WSES-10Q-231).
2. SI Calculation W-ENTP-13Q-316, "ANO-2 Pressurizer Heater Penetration Finite Element Model with Instrument Nozzle, " Rev. 0.
3. ASME Boiler and Pressure Vessel Code, Section II, Part D, 1995 Edition with 1997 Addenda
4. PIPE-TS2, Structural Integrity Associates, Version 1.01.
5. Email from Richard Smith (for WSI) to Art Deardorff, "Analysis of the WSI Mid-Wall Mockup Heat Transfer,"3/8/2005 (SI File WSES-10Q-232).