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Evaluation of Reactor Vessel Surveillance Data Pertinent to the Fort Calhoun Reactor Vessel Beltline Materials

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Basis for Prediction of RT_{PTS}
for the Fort Calhoun RPV

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Table of Contents

List of Tables

List of Tables (continued)

List of Figures

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Objective

The objective of this report is to demonstrate that the Fort Calhoun reactor pressure vessel is unlikely to exceed the Pressurized Thermal Shock (PTS) screening criteria through the end of the current license (August 9, 2013). This evaluation is based on the use of Position 2.1 of Regulatory Guide 1.99 to justify reduction of the standard deviation for shift by one-half. The PTS screening criteria projections are based on conservative values of neutron fluence that were calculated using the methods of the U.S. Nuclear Regulatory Commission's Draft Regulatory Guide DG-1053, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence". The approach used for calculating RT_{PTS} is consistent with present regulations.

Introduction and Background

The Fort Calhoun reactor vessel was fabricated by Combustion Engineering in Chattanooga, Tennessee during the time period 1966 to 1969. The vessel shell was fabricated using steel plates purchased to SA-533 Grade B, Class 1 requirements. The plates were joined together using automatic submerged arc welding using copper-coated electrodes. The primary coolant nozzles and the vessel flange were fabricated using forgings purchased to SA-508 Class 2 requirements. The forgings were joined to the vessel shell using automatic and manual submerged arc welding.

The reactor vessel shell, primary coolant nozzles and the vessel flange were designed to operate at high temperatures and pressures. The reactor vessel beltline materials were also designed for exposure to the fast neutrons generated in the reactor core. The material purchase specifications together with the forming, welding, and post-weld heat treatment processes were intended to provide for a high level of fracture toughness. The pre-service inspection and hydrostatic testing processes were intended to minimize the presence of fabrication-induced defects that could grow during the service lifetime. During the lifetime of the reactor vessel, periodic in-service inspections are conducted to look for defect indications in the vessel welds. In addition, a reactor vessel surveillance program is

maintained throughout the life of the vessel to monitor the effect of neutron irradiation on the beltline materials.

Given the fact that the beltline welds in the Fort Calhoun vessel were fabricated using copper coated electrodes, the copper content in those welds is high (relative to vessel welds fabricated using non-copper coated electrodes). Such high copper welds have been shown to be more sensitive to the hardening effects of fast neutron irradiation than vessels fabricated during the mid- and late-1970's using non-copper coated welding electrodes. Neutron irradiation causes a reduction of the fracture toughness in the reactor vessel beltline materials. This toughness reduction is manifested as a shift in the reference temperature, RT_{NDT}, to a higher value. The shift increases as a function of the fast neutron fluence and chemical content (specifically the copper and nickel content in Regulatory Guide 1.99, Revision 02). The magnitude of the shift is sensitive to the product form (e.g., plate or weld material).

The methodology for predicting shift that is currently acceptable to the NRC is provided in 10CRF50.61, "Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Events", and Regulatory Guide 1.99, Revision 02, "Radiation Embrittlement of Reactor Vessel Materials". These two documents plus a handout entitled "Evaluation and Use of Surveillance Data" from a November 12, 1997 NRC-Industry Meeting provide a set of NRC requirements and guidelines for using relevant and credible surveillance data to refine predictions of the shift in RT_{NDT} and calculation of the adjusted reference temperature, ART. (Values of ART are obtained using the sum of the initial RT_{NDT}, the shift of RT_{NDT} with irradiation, and a margin term.) In the longer term, work is proceeding on the development of an improved methodology for predicting values of ART. This effort entails a cooperative NRC/Industry program to revise ASTM Standard E900.

The approach being taken in this document is to apply Position 2.1 of Regulatory Guide 1.99 to available surveillance data. (Position 2.1 provides a procedure for adjusting the chemistry factor used to predict shift and for reducing the standard deviation for shift in the margin term.) Several weld wire heats in various combinations were used in the beltline welds for the Fort Calhoun vessel. Therefore, numerous sources of surveillance data will be evaluated to give the broadest possible picture of the irradiation performance for the Fort

Calhoun beltline welds. Data that will be reviewed for applicability to Ft. Calhoun are Diablo Canyon Units 1 and 2, McGuire Unit 1, Calvert Cliffs Unit 1 (including a supplemental surveillance program weld), and others that used electrode heat 12008 plus another to produce the surveillance weld. The results of this Position 2.1 analysis can then be used to calculate the adjusted reference temperature, ART, taking the adjusted chemistry factor and the reduced standard deviation for shift from the analysis. The Position 2.1 analysis will be augmented using NRC supplemental guidance.

Description of Fort Calhoun Reactor Vessel Beltline Materials

The Fort Calhoun reactor vessel beltline materials and surveillance materials are described in Table 1. The first column gives the plate code or the weld seam identification. The second column gives the heat number for the plate or welding electrode. The third column gives the flux type and lot number for the welds. The fourth column gives the chemistry factor based on the best estimate copper and nickel content. (The weld chemistry factor values are from Reference 14.)

The Fort Calhoun beltline consists of the intermediate and lower shell courses of the reactor vessel. Plates D-4802-1, D-4802-2, and D-4802-3 comprise the intermediate shell course. Plates D-4812-1, D-4812-2, and D-4812-3 comprise the lower shell course. The plates and shell courses were joined together using automatic submerged arc welding using Mil B4 copper coated electrodes and Linde 1092 or Linde 124 flux. Weld seams 2-410 A/C (where "A/C" means seams A, B, and C) are the axial welds between the plates to form the intermediate shell. Weld seams 3-410 A/C are the axial welds between the plates to form the lower shell. Weld seam 9-410 is the circumferential weld between the intermediate and lower shell course. Weld seams 2-410 A/C and 9-410 were deposited using the single arc process. Weld seams 3-410 A/C were deposited using the tandem arc process.

Table 1 also provides a description of the Fort Calhoun surveillance program plate and weld material. The surveillance plate was obtained from plate D-4802-2. The surveillance weld was fabricated using the same welding process as was used for weld seam 9-410 but a different heat of wire.

The beltline materials are evaluated using Regulatory Guide 1.99, Revision 02 to identify the limiting material at end of the license period. The limiting material is the beltline plate or weld with the highest ART value. The limiting materials in the Fort Calhoun vessel beltline are from the lower shell course welds. As stated in the Introduction, the objective of this evaluation is to apply Position 2.1 of Regulatory Guide 1.99 to surveillance data that are applicable to the limiting material, the lower shell course welds. The results of this Position 2.1 analysis can then be used to calculate the adjusted reference temperature, ART, at the end of the license period taking the adjusted chemistry factor and the reduced standard deviation for shift from the analysis.

Description of Surveillance Data Relevant to Fort Calhoun

In Table 1, the weld wires used to fabricate the lower shell course welds in the Fort Calhoun vessel were identified as heat numbers 12008, 13253, and 27204. The approach taken was to match up those heats or combination of heats with those used to fabricate the surveillance welds in other reactor vessels manufactured by Combustion Engineering during a similar period of time.

The surveillance weld matches are identified in Table 2. The matches are based on CEOG Report CE NPSD-1119 (Reference 15). [Note: The CEOG report did not cite any matches with foreign plants. However, there is one potential foreign source for which the data have not been released.] Data from five PWR surveillance programs (References 1 through 13) were identified as likely sources of information relative to the three heats from weld seam 3-410 A/C. Data determined to be applicable to Fort Calhoun are D.C. Cook Unit 1, Diablo Canyon Units 1 and 2, McGuire Unit 1, Salem Unit 2, and a supplemental surveillance program weld. Data from three BWR surveillance programs were also identified, but not used. Analysis of those BWR data was not done given the limited number of measurements and the uncertainty regarding the effects of differences in irradiation environment between the BWRs and the Fort Calhoun vessel.

The data from the five PWR surveillance programs and from the Fort Calhoun surveillance program were compiled from the database assembled for the previously cited ASTM E900 effort (Reference 18). That database had been reviewed, updated and augmented by knowledgeable individuals from the Industry and, therefore, provides a credible source of

information for each surveillance program. In addition the individual post-irradiation test reports were reviewed to the extent possible to assess the reasonableness of the data updates.

The six surveillance program data sets are provided in Tables 3 through 8. Each table contains the surveillance capsule identity, the measured shift, the reported neutron fluence, and the irradiation temperature. [Note: The irradiation temperature for the surveillance specimens was taken as that of the reactor coolant cold leg from the E900 database.]

Regulatory Position 2.1 Analysis of Relevant Surveillance Data

The objective of this section is to analyze the surveillance data in accordance with Position 2.1 of Regulatory Guide 1.99, Rev. 2, "Radiation Embrittlement of Reactor Vessel Materials". The Position 2.1 analysis will be augmented using the guidance provided by the NRC (Reference 17). The guidance provides a set of NRC review requirements and guidelines for using relevant and credible surveillance data from other reactor vessels to refine predictions of the shift in RT_{NDT} and calculation of the adjusted reference temperature, ART. Position 2.1 of Regulatory Guide 1.99 is applied to available surveillance data that were identified in the preceding section as relevant to the beltline welds in the Fort Calhoun vessel.

1. Credibility of Surveillance Data:

   Regulatory Guide 1.99 presents five credibility criteria by which surveillance data from a given reactor are judged before the surveillance data can be used in place of Regulatory Position 1. The five criteria are discussed in turn below:

   Criterion 1: "Materials in the capsules should be those judged most likely to be controlling with regard to radiation embrittlement according to the recommendations of this guide."

   The chemistry factors for each of the three beltline welds (determined using Table 1 of Regulatory Guide 1.99) range from 89 °F to 231 °F. [Note: The highest chemistry factor for the beltline plates is less than the lowest beltline

weld, 89 °F. Therefore, the beltline plates will not limit vessel operation and are excluded from the subsequent discussion.] The surveillance weld was fabricated using weld wire heat #305414 with Linde 1092 flux lots #3947 and #3951. It was made from different welding consumables than those used for the Fort Calhoun beltline welds. The surveillance weld is representative of but not identical to the beltline welds, so it does not meet Criterion 1. Therefore, it can not be used in a Position 2.1 analysis of the Fort Calhoun beltline welds. The focus of this report is on the use of surveillance weld data that were fabricated using the same weld wire heats as were used in the Fort Calhoun beltline welds; i.e., surveillance weld data that meet Criterion 1 for the Fort Calhoun beltline welds. As can be seen the surveillance program welds listed in Table 2 include most of the weld heats listed in Table 1. The one not represented, weld wire heat #51989, has a chemistry factor of 89 °F and thus is not a controlling beltline weld. The surveillance welds in Table 2 include the individual heats of controlling beltline weld materials and, therefore, satisfies the first criterion. [Note, however, that there are not surveillance welds representing all of the possible combinations of heats.]

Criterion 2: "Scatter in the plots of Charpy energy versus temperature for the irradiated and unirradiated conditions should be small enough to permit the determination of the 30-foot-pound temperature and the upper-shelf energy unambiguously."

As part of the effort to review the surveillance data for the ASTM E900 effort, all of the data were computer curve fit by Modeling and Computing Services as part of an effort sponsored by the U.S. Nuclear Regulatory Commission (Reference 18). Barring significant disagreement with the originally reported data, the computer curve fit results (index temperature and transition temperature shift) were used for the E900 effort and reported in that database. Therefore, it can be said that the individual test results for the materials data applied from Table 2 exhibited behavior consistent with pressure vessel materials, scatter was well within expected ranges, and there were no difficulties experienced in deriving the 30 foot-pound temperature. The second criterion is satisfied.

Criterion 3: "When there are two or more sets of surveillance data from one reactor, the scatter of RT_{NDT} shift values about a best-fit line drawn as described in Regulatory Position 2.1 normally should be less than 28 °F for welds and 17 °F for base metal. Even if the fluence range is large (two or more orders of magnitude), the scatter shall not exceed twice those values. Even if the data fail this criterion for use in shift calculations, they may be credible for determining decrease in upper-shelf energy if the upper shelf can be clearly determined, following the definition given in ASTM E185-82."

The weld metal shift measurements for the materials in Table 2 were evaluated individually against this criterion and the results of that evaluation are provided in the following sections.

Criterion 4: "The irradiation temperature of the Charpy specimens in the capsule should match the vessel wall temperature at the cladding/base metal interface within ±25 °F."

This criterion could not be addressed using temperature monitor data because there was an inconsistent use of monitors among the various surveillance programs. However, both NRC guidance (Reference 17) and the ASTM E900 work (Reference 18) used the reactor coolant inlet temperatures as a best estimate for the irradiation temperature of the Charpy specimens in the capsule. (Implicit in this approach is the assumption that Criterion 4 will be met. It is based on the premise that the reactor coolant will cool the vessel wall and the adjacent surveillance specimens the same.) In the data analysis that follows, the reactor coolant inlet temperatures from the ASTM E900 database (Reference 18) was used to provide an estimate of the temperature of the Charpy specimens. Thus Criterion 4 is implicitly satisfied.

Criterion 5: "The surveillance data for the correlation monitor material in the capsule should fall within the scatter band of the data base for that material."

There are limited sets of correlation monitor material (termed standard reference material in the Fort Calhoun vessel) data from the various surveillance capsules. For Fort Calhoun, the correlation monitor material measurements were addressed in Reference 8. For the other surveillance data, no such analysis could be performed. Therefore, only the Fort Calhoun correlation monitor material measurements can be stated to have satisfied Criterion 5.

In summary, the surveillance data are shown to satisfy four of the criteria above and the data are being assessed individually for Criterion 3 in the section that follows (Analysis of Surveillance Data). Therefore, the surveillance data are acceptable for use following Position 2.1 of Regulatory Guide 1.99, Revision 2.

2. Analysis of Surveillance Data

The following analysis utilizes the ratio method of Regulatory Guide 1.99, Revision 2. The ratio method is based on the relative chemistry factors. Regulatory Guide 1.99 states that, "if there is clear evidence" of a difference in copper and nickel content, the measured shift should be adjusted by multiplying by the ratio of the chemistry factors for the vessel weld to that of the surveillance weld (i.e., the ratio method). For purposes of this evaluation, "clear evidence" was converted to the following criterion:

> If the difference between the chemistry factors for the two welds is more than 5% of the lower chemistry factor, then the ratio method shall be applied. If the difference is 5% or less, then there is no clear distinction and the ratio method is not applied.

References 14 and 15 were used to obtain best estimate copper and nickel contents for the weld wire heats so that chemistry factors could be computed for the Fort Calhoun welds.

D.C. Cook Unit 1- The Cook surveillance weld was fabricated using weld wire heat 13253. The chemistry factors for the Cook surveillance weld and the Fort Calhoun vessel weld are 206.4 °F and 189.05 °F, respectively. The Cook shift

measurements in Table 3 were adjusted for chemistry factor differences using the ratio 189.05 °F /206.4 °F= 0.916.

The chemistry factor derived based on the four capsule results is 122.6 °F. The predicted shifts based on this chemistry factor were compared to the adjusted Charpy shifts. The adjusted minus predicted shifts for capsules Y and U are well in excess of σ_Δ for welds (28 °F). The chemistry factor was re-derived based on three capsule results, where capsule U was excluded because it was the most overpredicted value. The resultant chemistry factor value based on capsules T, X and Y is 142.8 °F, which is higher than the chemistry factor value based on all four capsules. The adjusted minus predicted shifts for those three capsules are within σ_Δ for welds (28 °F). The adjusted minus predicted shift for capsule U is greater than σ_Δ but is negative (i.e., conservative). Therefore, the Cook Unit 1 surveillance data are predictable when the capsule U results are excluded. The derived chemistry factor of 142.8 °F is much lower than the values for the surveillance weld (206.4 °F) from Table 1 and for the Fort Calhoun vessel weld (189.05 °F).

Diablo Canyon Unit 1- The Diablo Canyon surveillance weld was fabricated using weld wire heat 27204. The chemistry factors for the Diablo Canyon surveillance weld and the Fort Calhoun vessel weld are 221.8 °F and 226.81 °F, respectively. The Diablo Canyon shift measurements in Table 4 were not adjusted using the ratio method given the lack of a clear difference in the chemistry factors. The chemistry factor derived based on the two capsule results is 217.0 °F. The predicted shifts based on this chemistry factor were compared to the measured Charpy shifts. The measured minus predicted shift for capsule S (fluence of 2.84E18 n/cm^2) is in excess of σ_Δ for welds (28 °F), but the difference is negative (i.e., conservative). The adjusted minus predicted shifts for capsule Y (fluence of 9.41E18 n/cm^2) is less than σ_Δ. The derived chemistry factor of 217.0 °F is similar to the values for the surveillance weld (221.8 °F) from Table 1 and for the Fort Calhoun vessel weld (226.81 °F).

The chemistry factor is also calculated based on the originally reported fluence values and the measured shifts. That resulted in a value of 211.8 °F that tends to reduce the difference between the predicted minus measured values, but not

enough to prevent capsule S to be in excess of σ_Δ. A similar analysis was done in Table 9 using preliminary data on weld heat #27204 irradiated in another reactor vessel. The derived chemistry factor was similar (213.6 °F) and the predicted minus measured values for the two higher neutron fluences were less than σ_Δ (18.2 °F and 2.2 °F). The highest fluence measurement had a negligible difference (2.2 °F) between the predicted and measured value. The data in Table 9 are, therefore, predictable for the two high fluence measurements but not for the one low fluence measurement.

Diablo Canyon Unit 2- The Diablo Canyon surveillance weld was fabricated using weld wire heat 12008 with 21935. The chemistry factors for the Diablo Canyon surveillance weld and the best estimate chemistry for that heat are 211.1 °F and 208.6 °F, respectively. The Diablo Canyon shift measurements in Table 5 were not adjusted using the ratio method given the lack of a clear difference in the chemistry factors.

The chemistry factor derived based on the three capsule results is 209.0 °F. The predicted shifts based on this chemistry factor were compared to the measured Charpy shifts. The measured minus predicted shifts for the three capsules are all less than σ_Δ. Therefore, the Diablo Canyon Unit 2 surveillance data are predictable. The derived chemistry factor of 209.0 °F is similar to the values for the surveillance weld (211.1 °F) from Table 1 and for the best estimate chemistry for that heat (208.6 °F).

Fort Calhoun - The Fort Calhoun surveillance weld was fabricated using weld wire heat 305414. The chemistry factor for the Fort Calhoun surveillance weld is 194 °F. No adjustment to the chemistry factor was made because the data are not being related to any vessel weld; they are only being used to assess predictability of the Fort Calhoun surveillance weld data.

The chemistry factor derived in Table 6A based on the three capsule results is 229.0 °F. The predicted shifts based on this chemistry factor were compared to the measured Charpy shifts. The measured minus predicted shifts for the three capsules are all less than σ_Δ. Therefore, the Fort Calhoun weld surveillance data are

predictable. The derived chemistry factor of 229.0 °F is higher than the value for the surveillance weld (194 °F) in Table 1.

The Fort Calhoun surveillance plate was fabricated using heat A1768-1. The chemistry factor for the Fort Calhoun plate is 65 °F based on Table 2 of Regulatory Guide 1.99, Revision 2. No adjustment to the chemistry factor was made because there is no difference between the surveillance plate and the vessel plate chemistry. The data are being used to assess the predictability of the Fort Calhoun surveillance plate data.

The chemistry factor derived in Table 6B for the surveillance plate based on the three capsule results (where the longitudinal and transverse measurements were combined) is 72.0 °F. The predicted shifts based on this chemistry factor were compared to the measured Charpy shifts. The measured minus predicted shifts for the five measurements are all less than σ_Δ. Therefore, the Fort Calhoun plate surveillance data are predictable. The derived chemistry factor of 72.0 °F is similar to the Table 2 value (65 °F).

The standard reference material in the Fort Calhoun surveillance program was from HSST Plate 01. The chemistry factor for the plate is 131.7 °F using the reported chemical content from the E900 database with Table 2 of Regulatory Guide 1.99, Revision 2. No adjustment to the chemistry factor was made because there is no corresponding vessel plate chemistry. The data are being used to assess the predictability of the Fort Calhoun standard reference material data.

The chemistry factor derived in Table 6C for the standard reference material based on the two capsule results is 138.3 °F. The predicted shifts based on this chemistry factor were compared to the measured Charpy shifts. [Note: This goes well beyond the requirements of Regulatory Guide 1.99, Revision 2, Criterion 5 in which it is necessary only to show the data are within the scatterband of available measurements.] The measured minus predicted shifts for the two measurements are both less than σ_Δ. The derived chemistry factor of 138.3 °F is similar to the Table 2 value (131.7 °F). Therefore, the Fort Calhoun standard reference material data are predictable.

McGuire Unit 1- The McGuire surveillance weld was fabricated using weld wire heat 12008 with 20291. The chemistry factors for the McGuire surveillance weld and the best estimate chemistry for that heat combination are 204.1 °F and 200.4 °F, respectively. The McGuire shift measurements were adjusted for chemistry factor differences using the ratio 200.4 °F /204.1 °F = 0.982. [Note: The difference between the chemistry factors is insignificant. However, there are two corresponding Fort Calhoun vessel welds to which the McGuire data are being compared, so the ratio method is being used to help make that comparison. The 200.4 °F chemistry factor corresponds to the best estimate chemistry for that heat combination and not to the two corresponding Fort Calhoun vessel welds.]

The chemistry factor derived Table 7 based on the four capsule results is 152.8 °F. In order to be consistent with Reference 16 (i.e., in consideration of the underprediction of the Capsule U results), the chemistry factor was re-derived based on the three capsule results. The chemistry factor was determined to be 146.2 °F. The predicted shifts based on this chemistry factor were compared to the measured Charpy shifts. The measured minus predicted shifts for the three capsules are all less than σ_{Δ}. (The differential ranged from –0.8 °F to 2.5 °F for the data from capsules X, V and Y. The corresponding value for capsule U was 41.1 °F.) The derived chemistry factor of 146.2 °F is lower than the values for the surveillance weld (204.1 °F) from Table 1 and for the Fort Calhoun vessel weld (200.4 °F). Therefore, the McGuire Unit 1 surveillance data are predictable.

Salem Unit 2- The Salem surveillance weld was fabricated using weld wire heat 13253. The chemistry factors for the Salem surveillance weld and the Fort Calhoun vessel weld are 198.1 °F and 189.05 °F, respectively. The Salem shift measurements in Table 8 were not adjusted using the ratio method given the lack of a clear difference in the chemistry factors.

The chemistry factor derived Table 8 based on the three capsule results is 202.4 °F. The predicted shifts based on this chemistry factor were compared to the measured Charpy shifts. The measured minus predicted shifts for the three capsules are all less than σ_{Δ}. The derived chemistry factor of 202.4 °F is very similar to the values for

the surveillance weld (198.1 °F) from Table 1 and for the Fort Calhoun vessel weld (189.05 °F). Therefore, the Salem Unit 2 surveillance data are predictable.

Evaluation of Surveillance Data Credibility and Applicability to Fort Calhoun

The results of the preceding analysis are summarized in Tables 10 and 11. The derived chemistry factors are provided in Table 10 for each of the surveillance program welds that are relevant to the Fort Calhoun beltline welds. The derived values correspond to the best estimate chemistry for the weld wire heat(s) used to fabricate the surveillance program welds. The ratio method was applied where appropriate to adjust the chemistry of the specific surveillance program weld to the best estimate chemistry for the vessel weld. (See criterion used to define "appropriate" at the beginning of the "Analysis of Surveillance Data" section.) Also shown are the chemistry factors obtained using Table 1 of Regulatory Guide 1.99, Revision 2 for the surveillance weld and the best estimate chemistry for the weld wire heat.

The effect of neutron irradiation environment was addressed specifically by BGE, Duke Power and in a CEOG evaluation (see References 19, 20, and 21, respectively). The effect of neutron irradiation environment is taken to mean changes in measured transition temperature shift caused by differences in irradiation temperature, neutron flux and neutron energy spectrum. For the BGE and Duke evaluations (References 19 and 20), there was no expected influence of neutron flux or neutron energy spectrum given the use of only PWR surveillance data. The actual values of neutron flux and neutron energy spectrum were compared for the various plants being considered, and the values were within expected ranges for which no difference in irradiation behavior would be expected. The Duke evaluation entailed comparisons of data from two Westinghouse designed reactor vessels. The BGE evaluation entailed comparisons of data from a Combustion Engineering and a Westinghouse designed reactor vessel. For the CEOG evaluation (Reference 21), a statistical analysis of surveillance data from both Combustion Engineering and Westinghouse designed reactor vessels demonstrated that there was no significant effect of differences in the irradiation environment for vessel materials fabricated by Combustion Engineering. In this report, data from those two vessel designs were considered in the analysis. Therefore, there is no significant effect of irradiation environment expected relative to the results in Table 10.

The effect of irradiation temperature was explicitly considered in the BGE evaluation (Reference 19) using the rationale stated in Reference 17. That rationale assumes there is a 1.0 °F effect on the chemistry factor for each 1.0 °F difference in irradiation temperature. (The higher the irradiation temperature, the lower the chemistry factor would be, and vice versa, per Reference 17. Irradiation temperature is taken as the reactor coolant inlet temperature.) In this evaluation, the effect of irradiation temperature was considered in two ways. The first was to see if the derived chemistry factors in Table 10 varied consistently with irradiation temperature relative to the Regulatory Guide 1.99 chemistry factors. The reported reactor coolant cold leg temperatures are provided for information in each of the tables of surveillance data. For two of the surveillance data sets (McGuire 1 and Salem 2), the direction of the trend for the effect of irradiation temperature is consistent with the Reference 17 rationale. For three of the surveillance data sets Cook 1, Diablo Canyon 1 and Diablo Canyon 2), the direction of the trend for the effect of irradiation temperature is the opposite of the Reference 17 rationale. [Note: The time averaged reactor coolant inlet temperatures for four of the five surveillance data sets are between 533 °F and 542 °F. Those temperatures are in the same range as for Fort Calhoun (time averaged reactor coolant inlet temperatures of 527 °F to 538 °F for the three surveillance capsules, and 543 °F reactor coolant inlet temperature for current operation). Therefore, four of the five data sets would not require any adjustments for difference in irradiation temperature.]

The second way of considering the effect of irradiation temperature was to examine the standard reference material (SRM) data from Combustion Engineering designed surveillance capsules. The data (from Reference 18) are summarized in Figures 1 and 2 and detailed in Tables A1 and A2. The SRM material in each of the capsules evaluated is from the same source, HSST Plate 01. It was irradiated with the surveillance plate and weld materials in each of the Combustion Engineering plants. Post-irradiation test results are available from twelve capsules representing nine different plants. Table A1 describes the vessel, surveillance capsule identity, transition temperature shift, neutron fluence and irradiation temperature for each. The data are plotted against irradiation temperature in Figure 1. The measured shifts were normalized to $1X10^{19}$ n/cm^2 and compared to the Regulatory Guide 1.99, Revision 2 prediction. If increasing irradiation temperature did reduce shift, then the shift should be overpredicted with increasing temperature. Therefore, the value of "Measured - Predicted Shift" should get larger with increasing temperature. For

the temperature range of 522 °F to 552 °F there is no apparent trend. Figure 2 provides the same data plot without the normalization; again there is no apparent trend with irradiation temperature. These data are from a single material irradiated in nine different reactor vessels at a wide range of irradiation temperatures. This suggests that irradiation temperature is not a significant variable for the temperature range of the data, 522 °F to 552 °F. This is consistent with the original premise of Regulatory Guide 1.99, Revision 2 that the prediction methodology of the Guide is valid between 525 °F and 590 °F. This does not preclude the existence of a temperature effect (e.g., that presumed in Reference 18), but it does demonstrate that irradiation temperature is not a major factor when using Position 2.1 of Regulatory Guide 1.99, Revision 2 with data in the range between 522 °F to 552 °F.

All of the surveillance materials are credible with respect to being equivalent to the Fort Calhoun materials. This equivalency is with respect to weld wire heat number, welding flux type, and welding process. The data were also evaluated with respect to the surveillance measurements being predictable within one σ_Δ of the predicted shift based on the derived chemistry factor. In the case of heat 27204 (Table 4), the low fluence measurement is significantly overpredicted. When examined in conjunction with preliminary results from a supplemental capsule (Table 9), two of the measurements are predictable within one σ_Δ of the predicted shift. The two predictable measurements are from the capsules with higher neutron fluence. Given that the Regulatory Position 2.1 approach was designed to give more weight to the higher fluence measurements, the overprediction of the lowest fluence measurement is not unexpected.

In the case of the D.C. Cook Unit 1 (Table 3) and McGuire Unit 1 (Table 7) capsule data, there was one set of capsule results in each case that exceeded the predictability limits. In both cases, the inconsistent set was excluded in order to derive the chemistry factor.

In the case of D.C. Cook Unit 1 and Salem Unit 2, both surveillance programs used the same heat of weld material, 13253. The derived chemistry factors are equal to or less than the chemistry factors from Table 1 of Regulatory Guide 1.99, Revision 2. For the Diablo Canyon Units 1 and 2 data, the derived chemistry factors are very similar to the predicted chemistry factors from Regulatory Guide 1.99. In the case of McGuire Unit 1, the derived chemistry factor is much lower than the chemistry factor from Regulatory Guide 1.99. In all cases, the results were either conservative or comparable to predictions.

In Table 11, the Fort Calhoun surveillance program results are summarized. These data are credible and predictable. The derived and predicted chemistry factors in Table 11 are very consistent for the surveillance plate and for the SRM. The derived values are within 7°F. The derived and predicted chemistry factors for the surveillance weld are within 35 °F. The Fort Calhoun surveillance program results were further evaluated as follows:

1. One of the criteria of Regulatory Guide 1.99, Revision 2 is to ascertain that the SRM (correlation monitor) data are consistent with the trend of the database for that material. This is addressed in part in Figures 1 and 2 where it can be seen that the two Fort Calhoun results (at 527 °F and 538 °F) are as predictable as the other HSST Plate 01 data. It is further addressed in Table A2. The twelve sets of data from Combustion Engineering plants were evaluated following Position 2.1 of Regulatory Guide 1.99. Those data provide a derived chemistry factor of 130.3 °F. That value is to be compared with the predicted chemistry factor of 131.7 °F based on the best estimate copper and nickel for HSST Plate 01 and the derived chemistry factor of 138.3 °F from the Fort Calhoun measurements alone. The preceding results demonstrate that the Fort Calhoun SRM data are consistent with the trend of the database for that material. The similarity between the derived chemistry factors and the predicted value indicate that the Fort Calhoun vessel irradiation environment is comparable to that of the other Combustion Engineering designed plants.

2. An evaluation was performed to determine whether the Fort Calhoun surveillance weld data should be used in the Position 2.1 analysis of the Fort Calhoun beltline welds. The surveillance weld for Fort Calhoun was fabricated using a heat of wire that is not found in any of the beltline welds. It is unique in that it was purchased to a 0.60% nickel specification rather than the 0.0%, 0.75% and 1.00% nickel specifications used to purchase welding electrode heats for the Fort Calhoun beltline welds. The derived chemistry factor for the Fort Calhoun surveillance program weld data is higher than that predicted using Table 1 of Regulatory Guide 1.99, Revision 2. That is in contrast to the derived chemistry factors for the other welds in Table 10 that are consistently equal to or lower than the predicted chemistry factors. In other words, the surveillance weld data that correspond to the weld wire heats used in the Fort Calhoun beltline welds are conservatively predicted. There is no immediate explanation available for the

observation that the Fort Calhoun surveillance weld material (i.e., heat #305414) was not conservatively modeled in the formula developed for Regulatory Guide 1.99, Revision 2, whereas the 0.75% and 1.00% nickel specification heats were conservatively modeled. However, there are no Fort Calhoun beltline welds fabricated using the 0.60% nickel specification to which the Fort Calhoun surveillance weld data can be applied using the Position 2.1 analysis approach. Conversely, there are 0.75% and 1.00% nickel specification heats in the Fort Calhoun beltline welds to which the data listed in Table 10 can be applied using the Position 2.1 analysis approach.

The data in Table 10 encompass the four limiting weld wire heats used in the beltline welds of the Fort Calhoun reactor vessel. (There is one heat, 51989, in the beltline that has a much lower predicted sensitivity to irradiation than the four heats noted in Table 10. Heat 51989 is never expected to become a limiting beltline material.) The surveillance data coverage by weld seam is as follows:

Welds 3-410 A/C:	D.C. Cook 1 heat 13253, Diablo Canyon 1 heat 27204, Diablo Canyon 2 heat 12008 (with 21935), McGuire 1 heat 12008 (with 20291), and Salem 1 heat 13253.
Weld 9-410:	McGuire 1 heat 20291 (with 12008).
Welds 2-410 A/C:	No heat specific data. [Note: Heat 51989 is not a limiting material and requires no further consideration.]

Position 2.1 of Regulatory Guide 1.99, Revision 2 allows one to use credible surveillance data to determine the adjusted reference temperature. This is done by computing a value for the chemistry factor and then using half the normal value for σ_Δ to calculate the margin. Based on the preceding, there are credible surveillance data for each of the limiting heats used in the Fort Calhoun reactor vessel beltline. For each surveillance weld, a chemistry factor was derived as described previously (using the ratio method to the extent applicable). The derived chemistry factors obtained were less than or equal to the value obtainable from Table 1 of Regulatory Guide 1.99, Revision 2. Position 2.1 states that "if this procedure gives a higher value of adjusted reference temperature than that given by using the procedures of Regulatory Position 1.1 (i.e., Table 1 of Regulatory Guide 1.99, Revision 2),

the surveillance data should be used. If this procedure gives a lower value, either may be used." Given the availability of credible surveillance data that show the Regulatory Position 1.1 chemistry factors to be conservative, those chemistry factors may be used. In the calculation of the margin, availability of credible surveillance data justifies using half the normal value for σ_Δ when determining the adjusted reference temperature.

Calculation of RT_{PTS}

The limiting beltline material for the Fort Calhoun vessel is that from the lower shell axial welds, 3-410 A/C. The preceding analysis has demonstrated that there are credible surveillance data available for the heats of weld materials used to fabricate those axial welds. These five sets of credible data pertain to each of the heats used for the lower shell axial welds although not for each possible combination of heats. There are data for the 1% nickel alloy welds (i.e., heat 27204) that yielded a chemistry factor of 213.6 °F versus a predicted chemistry factor (from Table 1 of Regulatory Guide 1.99, Revision 02) of 221.8 °F. There are separate data for the one combination that has the highest predicted chemistry factor from Table 1 of Regulatory Guide 1.99, Revision 2, heat 27204 with 12008. Those data yielded chemistry factors of 209.0 °F and 146.2 °F versus predicted chemistry factors (from Table 1 of Regulatory Guide 1.99, Revision 02) of 211.1 °F and 204.1 °F. For all five sets of credible surveillance data, all of the derived chemistry factors were less than the highest predicted chemistry factor, 231.06 °F.

There is no guidance in either Regulatory Position 2.1 of Regulatory Guide 1.99, Revision 02 or Reference 17 for determining a revised chemistry factor from credible surveillance data when multiple combinations of heats are involved. Therefore, the highest predicted chemistry factor, 231.06 °F, is conservatively assumed for the calculation of RT_{PTS}. Given the availability of credible surveillance data for each of the heats involved it is justified to use half the normal value for σ_Δ to calculate the margin when determining the adjusted reference temperature.

Provided below is the determination of the adjusted reference temperature for the limiting beltline material predicted for the end of the current license for Fort Calhoun (August 9, 2013). The neutron fluence was conservatively determined to be 1.728 $x10^{19}$ n/cm^2 (E>1Mev) for that date using an unbiased estimate (see Reference 22). The fluence was

calculated using the methods of the U.S. Nuclear Regulatory Commission's Draft Regulatory Guide DG-1053, "Calculational and Dosimetry Methods for Determining Pressure Vessel Neutron Fluence". The RT_{PTS} calculation was performed as follows:

$$RT_{PTS} = \text{Initial } RT_{NDT} + \text{Shift} + \text{Margin}$$

where:

- Initial RT_{NDT} = - 56 °F (generic value for CE welds)

- Shift = Chemistry Factor X Fluence Factor
  - Chemistry Factor (CF) = 231.06 °F (highest predicted value for welds 3-410 A/C)
  - Fluence factor (FF) is a function of neutron fluence, f, in units of 1×10^{19} n/cm^2
  - $FF = f^{(.28 - 0.1 \times \log f)}$
  - Neutron Fluence = 1.728×10^{19} n/cm^2 (E>1Mev) at end of license (August 9, 2013)

- Margin = $2(\sigma_i^2 + \sigma_\Delta^2)^{1/2}$
  - σ_Δ = 28 °F/2 = 14 °F (half the value for welds)
  - σ_i = 17 °F (for generic CE welds)
  - $2(\sigma_i^2 + \sigma_\Delta^2)^{1/2} = 2(17\ °F^2 + 14\ °F^2)^{1/2} = 2(17^2 + 14^2)^{1/2}$
  - Margin = 44.0 °F

Therefore, the adjusted reference temperature for Fort Calhoun is determined as follows:

$$RT_{PTS} = -56\ °F + 231.06\ °F \times f^{(.28 - 0.1 \times \log f)} + 44.0\ °F$$

For the end of the current license for Fort Calhoun (August 9, 2013), the RT_{PTS} is:

$$RT_{PTS} = -56\ °F + 265.8\ °F + 44.0\ °F = 253.8\ °F$$

This projected value is less than the PTS screening criteria values for axial welds of 270 °F.

Conclusions

1) There is no significant effect of irradiation environment expected relative to the results in Table 10.

2) The Fort Calhoun surveillance program data are credible and predictable as summarized in Table 11.

3) For each surveillance weld the derived chemistry factor was less than or equal to the value obtainable from Table 1 of Regulatory Guide 1.99.

4) Credible surveillance data show the Table 1 chemistry factors to be conservative.

5) Given the preceding it is justified to use half the normal value for σ_Δ to calculate the margin when determining the adjusted reference temperature for the Fort Calhoun vessel beltline materials.

6) The projected value of RT_{PTS} is 253.8 °F at end-of–license. This was determined using half the normal value for σ_Δ (28°F/2 = 14°F) and the limiting material chemistry factor of 231.06 °F.

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21. "Application of Reactor Vessel Surveillance Data for Embrittlement Management", Combustion Engineering Owners Group Report CEN-405-P, Revision 3, September 1996.

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Table 1
Identification of Reactor Vessel Plates and Welds in the Fort Calhoun Reactor Vessel Beltline

Plate or Weld Identification	Plate or Weld Electrode Heat No.	Weld Flux Type and Lot No.	Chemistry Factor (°F)[a]
Plate D4802-1	C2585-3	N/A	82.2
Plate D4802-2	A1768-1	N/A	65
Plate D4802-3	A1768-2	N/A	73.1
Plate D4812-1	C3213-2	N/A	83
Plate D4812-2	C3143-2	N/A	65
Plate D4812-3	C3143-3	N/A	65
Surveillance Plate D4802-2	A1768-1	N/A	72.0[c]
2-410 A/C	51989	Linde 124, #3687	89.03
3-410 A/C	12008 & 13253 (T)[b]	Linde 1092, #3774	208.68
3-410 A/C	13253 (T)[b]	Linde 1092, #3774	189.05
3-410 A/C	12008 & 27204 (T)[b]	Linde 1092, #3774	231.06
3-410 A/C	27204 (T)[b]	Linde 1092, #3774	226.81
9-410	20291	Linde 1092, #3833	188.41
Surveillance Weld	305414	Linde 1092, #3947 and #3951	194

Notes:
a) Chemistry Factor from Table 1 or 2 of Regulatory Guide 1.99, Revision 02.
b) "T" denotes a tandem arc weld; other welds are single arc.
c) Chemistry Factor as derived based using surveillance measurements in Table 6B of this report.

Table 2
Weld Electrode Identification for Reactor Vessel Surveillance Program Welds Fabricated by Combustion Engineering

Reactor Vessel	Weld Electrode Heat No.	Flux Type and Lot No.
DC Cook 1	13253	Linde 1092, #3791
Cooper	20291	Linde 1092, #3833
Diablo Canyon 1	27204	Linde 1092, #3714
Diablo Canyon 2	12008 & 21935	Linde 1092, #3869
Fitzpatrick	12008 & 13253	Linde 1092, #3774
Ft. Calhoun	305414	Linde 1092, #3947,3951
McGuire 1	12008 & 20291	Linde 1092, #3854
Pilgrim	12008 & 20291	Linde 1092, #3833
Salem 2	13253	Linde 1092, #3774,3833

Table 3

Test Results from the D.C. Cook Unit 1 Reactor Vessel Surveillance Program (Surveillance Weld Wire Heat No. 13253)

Capsule Identity	Charpy Shift, °F	Neutron Fluence, n/cm^2	Irradiation Temperature, °F
T	70	2.69E18	537
X	146	8.13E18	537*
Y	184	1.23E19	537
U	109	1.77E19	537

* not reported; assumed to be same as other reported values

Capsule Identity	Adjusted Charpy Shift, °F	(FF) x Adjusted Shift	Fluence Factor (FF)	(FF)^2	Adjusted – Predicted** Shift, °F
T	64.1	41.2	.6424	.4127	**64.1-91.7=-27.6**
X	133.7	125.9	.9419	.8872	**133.7-134.5=-0.8**
Y	168.5	178.2	1.0577	1.1187	**168.5-151.0=17.5**
U	99.8	115.5	1.1569	1.3383	**99.8-165.2=-65.4**

$CF_{(ALL)}$=460.8/3.7569= 122.6 °F Σ=460.8 Σ =3.7569

$CF_{(w/o\ U)}$=345.3/2.4186= 142.8 °F Σ =345.3 Σ =2.4186

** Predicted using $CF_{(w/o\ U)}$= 142.8 °F

Table 4

Test Results from the Diablo Canyon Unit 1 Reactor Vessel Surveillance Program (Surveillance Weld Wire Heat No. 27204)

Capsule Identity	Charpy Shift, °F	Neutron Fluence, n/cm^2	Irradiation Temperature, °F
S	113	2.84 E18 (3.05*)	539
Y	233	9.41E18 (10.2*)	540

* neutron fluence per Surveillance Program test report

Capsule Identity	Charpy Shift, °F	(FF) x Shift	Fluence Factor (FF)	(FF)^2	Measured - Predicted Shift, °F
S	113	74.2	.6562	.4306	**113-142.5=-29.5**
Y	233	229.0	.9830	.9663	**233-213.4=19.6**

CF=303.1/1.3968= 217.0 °F Σ =303.1 Σ =1.3968

Capsule Identity	Charpy Shift, °F	(FF) x Shift	Fluence Factor (FF)**	(FF)^2	Measured - Predicted Shift, °F
S	113	76.2	.6745	.4550	**113-142.9=-29.9**
Y	233	234.3	1.0055	1.0111	**233-213=20**

CF**=310.5/1.4661= 211.8 °F Σ =310.5 Σ =1.4661

**Based on neutron fluence per Surveillance Program test report.

Table 5

Test Results from the Diablo Canyon Unit 2 Reactor Vessel Surveillance Program (Surveillance Weld Wire Heat No. 12008/21935)

Capsule Identity	Charpy Shift, °F	Neutron Fluence, n/cm^2	Irradiation Temperature, °F
U	173	3.65E18	542
X	203	9.16E18	541
Y	211	1.32E19	540

Capsule Identity	Charpy Shift, °F	(FF) x Shift	Fluence Factor (FF)	$(FF)^2$	Measured - Predicted Shift, °F
U	173	124.8	.7216	.5207	**173-150.8=22.2**
X	203	198.0	.9754	.9514	**203-203.9=-0.9**
Y	211	227.3	1.0772	1.1604	**211-225.1=-14.1**

CF=550.1/2.6325= 209.0 °F Σ =550.1 Σ =2.6325

Table 6A

Test Results from the Fort Calhoun Reactor Vessel Surveillance Program (Surveillance Weld Wire Heat No. 305414)

Capsule Identity	Charpy Shift, °F	Neutron Fluence, n/cm^2	Irradiation Temperature, °F
W225	210	5.53E18	527
W265	225	7.71E18	534
W275	219	1.28E19	538

Capsule Identity	Charpy Shift, °F	(FF) x Shift	Fluence Factor (FF)	$(FF)^2$	Measured - Predicted Shift, °F
W225	210	175.2	.8343	.6961	**210-191.1=18.9**
W265	225	208.6	.9270	.8593	**225-212.3=12.7**
W275	219	234.0	1.0687	1.1421	**219-244.7=-25.7**

CF=617.8/2.6975= 229.0 °F Σ =617.8 Σ =2.6975

Table 6B

Test Results from the Fort Calhoun Reactor Vessel Surveillance Program (Surveillance Plate Heat No. A1768-1)

Capsule Identity	Charpy Shift, °F (Lg,Tr)[a]	Neutron Fluence, n/cm^2	Irradiation Temperature, °F
W225	60, N/A	5.53E18	527
W265	74,70	7.71E18	534
W275	73,72	1.28E19	538

a) "Lg" is longitudinal and "Tr" is for transverse orientation Charpy data

Capsule Identity	Charpy Shift, °F (Lg,Tr)	(FF) x Shift	Fluence Factor (FF)	(FF)^2	Measured - Predicted Shift, °F
W225	60	50.1	.8343	.6961	**60-60.1=-0.1**
W265	74,70	68.6,64.9	.9270	.8593	**74-66.7=7.3** **70-66.7=3.3**
W275	73,72	78.0,76.9	1.0687	1.1421	**73-76.9=-3.9** **72-76.9=-4.9**

CF=338.5/4.6989= 72.0 °F Σ =338.5 Σ =4.6989

Table 6C

Test Results from the Fort Calhoun Reactor Vessel Surveillance Program (Standard Reference Material)

Capsule Identity	Charpy Shift, °F	Neutron Fluence, n/cm^2	Irradiation Temperature, °F
W225	124	5.53E18	527
W265	N/A	7.71E18	534
W275	141	1.28E19	538

* shift per Surveillance Program test report

Capsule Identity	Charpy Shift, °F	(FF) x Shift	Fluence Factor (FF)	$(FF)^2$	Measured - Predicted Shift, °F
W225	124	103.5	.8343	.6961	**124-115.4=8.6**
W275	141	150.7	1.0687	1.1421	**141-147.8=-6.8**

CF=254.2/1.8382= 138.3 °F Σ =254.2 Σ =1.8382

Table 7

Test Results from the McGuire Unit 1
Reactor Vessel Surveillance Program
(Surveillance Weld Wire Heat No. 12008/20291)

Capsule Identity	Charpy Shift, °F	Neutron Fluence, n/cm^2	Irradiation Temperature, °F
U	157	4.43E18	558
X	167	1.46E19	557
V	175	1.94E19	557
Y	190	2.93E19	557

Capsule Identity	Adjusted Charpy Shift, °F	(FF) x Adjusted Shift	Fluence Factor (FF)	$(FF)^2$	Adjusted - Predicted** Shift, °F
U	154.2	119.3	.7736	.5985	**154.2-113.1=41.1**
X	164.0	181.2	1.1049	1.2208	**164-161.5=2.5**
V	171.9	203.0	1.1811	1.3950	**171.9-172.7=-0.8**
Y	186.6	239.8	1.2851	1.6515	**186.6-187.9=-1.3**

$CF_{(ALL)}$=743.3/4.8658= 152.8°F Σ =743.3 Σ =4.8658

$CF_{(W/O\ U)}$=624.0/4.2673= 146.2 °F Σ =624.0 Σ =4.2673

**Predicted using $CF_{(W/O\ U)}$= 146.2 °F

Table 8

Test Results from the Salem Unit 2
Reactor Vessel Surveillance Program
(Surveillance Weld Wire Heat No. 13253)

Capsule Identity	Charpy Shift, °F	Neutron Fluence, n/cm²	Irradiation Temperature, °F
T	145	2.75E18	539
U	180	5.50E18	539
X	188	1.07E19	539

Capsule Identity	Charpy Shift, °F	(FF) x Shift	Fluence Factor (FF)	(Fluence Factor)²	Measured minus Predicted Shift, °F
T	145	94.0	.6480	.4199	**145-131.2=13.8**
U	180	149.9	.8328	.6936	**180-168.6= 11.4**
X	188	191.6	1.0189	1.0382	**188-206.2=-18.2**

CF=435.5 /2.1517= 202.4 °F Σ = 435.5 Σ = 2.1517

Table 9

Test Results from Diablo Canyon Unit 1 and Special Capsule (SC) Results (Weld Wire Heat No. 27204)

Capsule Identity	Charpy Shift, °F	Neutron Fluence, n/cm^2	Irradiation Temperature, °F
DC1-S	113	2.84 E18	539
DC1-Y	233	9.41E18	540
SC	247	1.70E19	533

Capsule Identity	Charpy Shift, °F	(FF) x Shift	Fluence Factor (FF)	(FF)^2	Measured - Predicted Shift, °F
DC1-S	113	76.2	.6745	.4550	**113-144.1=-31.1**
DC1-Y	233	234.3	1.0055	1.0110	**233-214.8=18.2**
SC	247	283.1	1.1461	1.3135	**247-244.8=2.2**
	CF=593.6/2.7795= 213.6 °F	Σ =593.6		Σ =2.7795	

Table 10

Derived Chemistry Factors for Reactor Vessel Surveillance Program Welds Relevant to Fort Calhoun

Reactor Vessel	Weld Electrode Heat No.	Flux Type and Lot No.	Derived Chemistry Factor, CF (°F)	RG 1.99 CF (°F) for Surveillance Weld Chemistry[a]	RG 1.99 CF (°F) for Best Estimate Weld Chemistry[b]
DC Cook 1	13253	Linde 1092 #3791	142.8	206.4	189.1
Diablo Canyon 1 and Supp. Capsule	27204	Linde 1092 #3714	211.8 to 217.0	221.8	226.8
Diablo Canyon 2	12008 & 21935	Linde 1092 #3869	209.0	211.1	208.6
McGuire 1	12008 & 20291	Linde 1092 #3854	146.2	204.1	200.4
Salem 2	13253	Linde 1092 #3774,3833	202.4	198	189.1

a) Chemistry Factor (CF) from Table 1 of Regulatory Guide 1.99 based on the copper and nickel content for the surveillance weld.

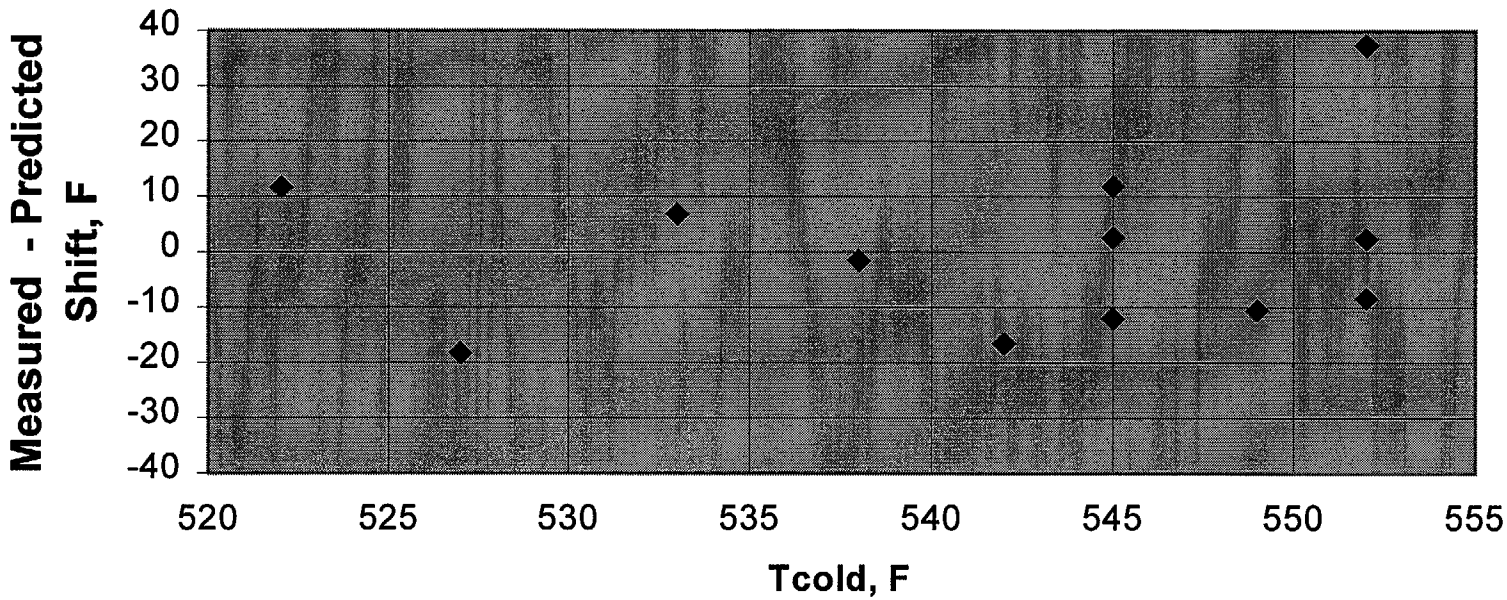
b) Chemistry Factor (CF) from Table 1 of Regulatory Guide 1.99 based on the best estimate copper and nickel content for the weld wire heat or combination of heats.

Table 11

Derived Chemistry Factors for Fort Calhoun Reactor Vessel Surveillance Materials

Material Ident.	Material Description	Derived Chemistry Factor (°F)	RG 1.99 Table 1 or 2 Chemistry Factor (°F)
Weld	Heat 305414, Linde 1092	229.0	194
Plate D4802-2	SA 533B Class 1	72.0	65
SRM	HSST Plate 01	138.3	131.7

Figure 1
Effect of Tcold on SRM Data
HSST Plate 01 Results
Normalized to 1E19 n/cm2



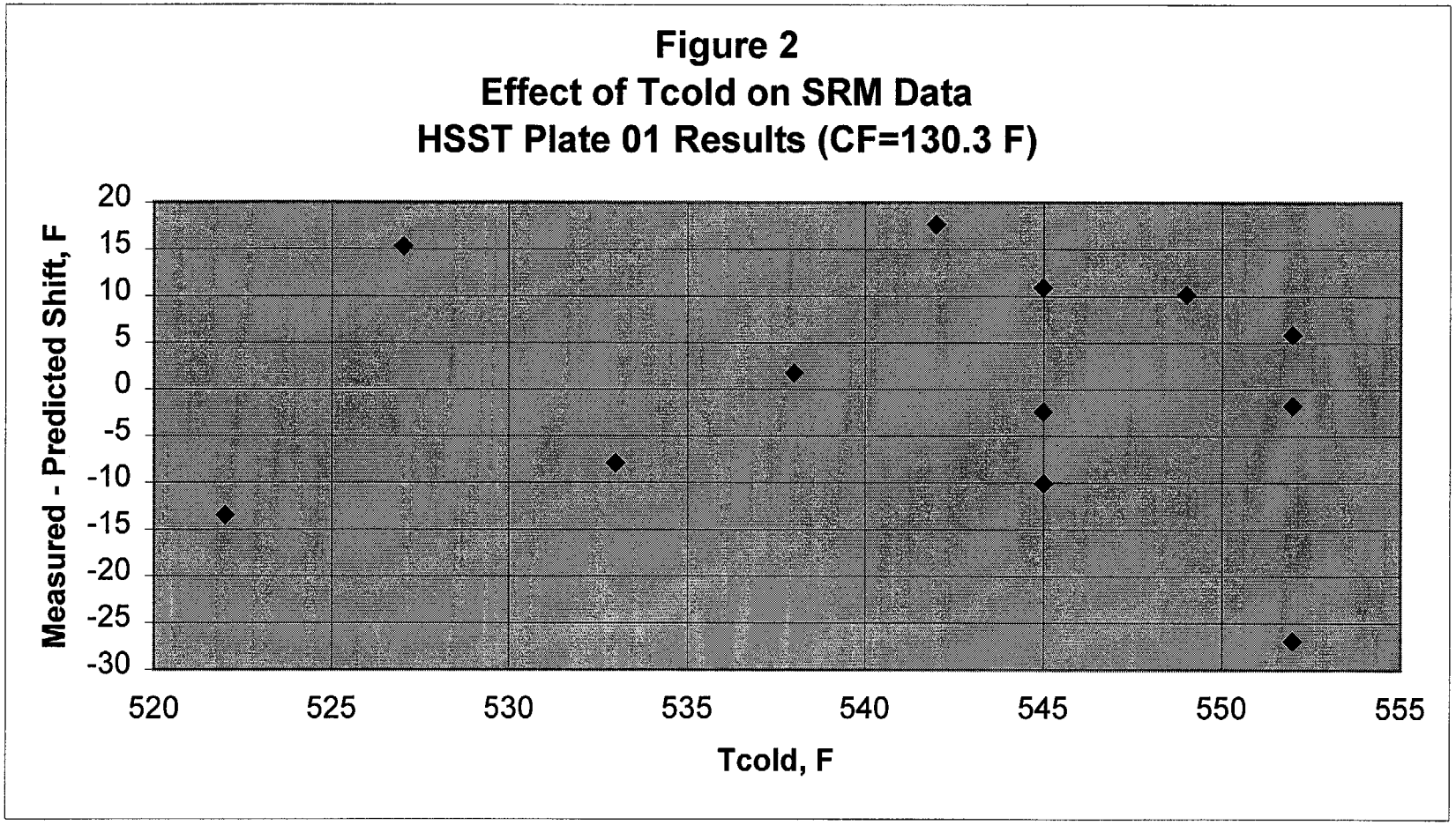


Figure 2
Effect of Tcold on SRM Data
HSST Plate 01 Results (CF=130.3 F)
Measured - Predicted Shift, F
20
15
10
5
0
-5
-10
-15
-20
-25
-30
520
525
530
535
540
545
550
555
Tcold, F

Table A1
Standard Reference Material Data from
Combustion Engineering Designed Surveillance Capsules

Reactor Vessel	Surveillance Capsule	SRM Material Identification	Charpy Shift (^{o}F)	Neutron Fluence (10^{19} n/cm^2)	Irradiation Temperature (^{o}F)
Calvert Cliffs 1	W263	HSST 01	101	0.59	545
Calvert Cliffs 2	W263	HSST 01	120	0.806	545
Fort Calhoun	W225	HSST 01	124* (116)	0.553	527
Fort Calhoun	W275	HSST 01	141* (162)	1.28	538
Millstone 2	W104	HSST 01	136	0.884	549
Maine Yankee	A25	HSST 01	137	1.76	522
Maine Yankee	W253	HSST 01	156	1.25	542
Palisades	W110	HSST 01	143	1.78	533
Palo Verde 1	W137	HSST 01	98	0.345	552
Palo Verde 2	W137	HSST 01	96	0.407	552
Palo Verde 3	W137	HSST 01	67*	0.364	552
St. Lucie 1	W104	HSST 01	129	0.716	545

*Shift per surveillance report

Table A2
Analysis of Standard Reference Materials

Irradiation Temperature, (°F)	Shift (°F)	(FF) x Shift	$(FF)^2$	Fluence (10^{19} n/cm^2)	Fluence Factor (FF)	Measured-Predicted Shift, (°F)
545	101	86.08	0.7264	0.59	0.85229	101 - 111.1 = -10.1
545	120	112.74	0.8827	0.806	0.93950	120 – 122.4 = -2.4
527	124*	103.46	0.6961	0.553	0.83434	124 – 108.7 = 15.3
538	141*	150.69	1.1422	1.28	1.06873	141 – 139.3 = 1.7
549	136	131.30	0.9321	0.884	0.9654	136 – 125.8 = 10.2
522	137	157.28	1.3348	1.76	1.1554	137 – 150.5 = -13.5
542	156	165.70	1.1282	1.25	1.0622	156 – 138.4 = 17.6
533	143	165.65	1.3418	1.78	1.1584	143 – 150.9 = -7.9
552	98	69.26	0.4994	0.345	0.70669	98 – 92.1 = 5.9
552	96	72.06	0.5635	0.407	0.75066	96 – 97.8 = -1.8
552	67*	48.30	0.5196	0.364	0.72085	67 – 93.9 = -26.9
545	129	116.91	0.8214	0.716	0.90630	129 – 118.1 = 10.9

*Shift per surveillance report

(FF) x Shift	$(FF)^2$	
Σ=1379.43	Σ=10.5882	CF=(1379.43)/ (10.5882)=130.3 °F