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SUBJECT: Forwards resolution of reactor vessel matls issue, revised response re PTS & bases for definition of weld chemistry of HBR vessel welds in future consideration of operating limits & characterization of radiation embrittlement.

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CP&L

Carolina Power & Light Company

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United States Nuclear Regulatory Commission
ATTENTION: Document Control Desk
Washington, DC 20555

H. B. ROBINSON STEAM ELECTRIC PLANT, UNIT NO. 2
DOCKET NO. 50-261/LICENSE NO. DPR-23
RESOLUTION OF REACTOR VESSEL MATERIALS
REVISED PRESSURIZED THERMAL SHOCK RESPONSE

Gentlemen:

This letter dockets the Carolina Power & Light Company (CP&L) response to the NRC letter dated August 26, 1986, requesting that the questions concerning the identity of the H. B. Robinson (HBR2) surveillance weld be resolved and the apparent inconsistencies of its weld chemistry explained. The information provided in the accompanying attachment was originally presented to the NRC in a meeting held on December 18, 1986. It resolves the issue referenced in the NRC request and establishes the bases upon which CP&L intends to define the weld chemistry of the HBR vessel welds in future consideration of operating limits and characterization of radiation embrittlement.

As this submittal demonstrates, CP&L's investigation has established the credibility of the originally claimed HBR2 surveillance weld identity. Furthermore, crucial parameters have been established to link this surveillance weld to the PTS controlling upper circumferential weld of the HBR2 vessel. As a result of the findings of this investigation and final resolution of the surveillance weld identity, some revision of the CP&L response to the Final Rule 10 CFR 50.61, "Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock (PTS) Events," is required. Therefore, the attachment to this submittal also amends our previous responses to 10 CFR 50.61 dated January 22, 1986, and February 4, 1986.

If you or your staff have any further questions concerning this subject, please contact Mr. R. W. Prunty at 919-836-7318.

Yours very truly,

S. R. Zimmerman

S. R. Zimmerman
Manager
Nuclear Licensing Section

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RESOLUTION OF REACTOR VESSEL MATERIALS

HBR2 SURVEILLANCE WELD ISSUE

BACKGROUND

In a report entitled, "Robinson 2 Reactor Vessel: Pressurized Thermal Shock Analysis for a Small Break LOCA", NP-3573-SR, dated August 1984, the Electrical Power Research Institute (EPRI) originally called the identity of the HBR surveillance block into question. A similar conclusion was reached by a Westinghouse study, "Evaluation of H. B. Robinson Reactor Vessel Beltline Region Weld Material Chemistry," in May 1983. Both conclusions were based solely upon the apparent inconsistency of the measured chemistry of the weld on the surveillance block with other copper and nickel values for that particular type of welding process and weld wire. Since the surveillance weld had been considered representative of the upper circumferential weld on the vessel, this had a direct impact on the chemistry assigned for that weld. However, at that time, the question of the surveillance weld identity was not crucial because the upper circumferential weld passed the proposed PTS screening criteria using either the surveillance weld chemistry or the alternate EPRI proposed chemistry.

During that period, the emphasis of CP&L's effort was focused upon defining the critical radiation embrittlement parameters for the lower circumferential weld which was independent of the surveillance weld issue. Preliminary studies had indicated that this weld was controlling for PTS concerns and could possibly exceed the proposed screening criteria. Considerable effort was expended to refine the fluence predictions through use of more sophisticated analyses of the fast neutron flux. These analyses resolved the early concerns by establishing reduced predictions of fluence at the lower weld which have subsequently been confirmed by a continuing monitoring program in cooperation with the NRC research organization and Oak Ridge National Laboratory. A parallel effort was also underway to establish the chemical properties of the lower weld by obtaining samples from a similar weld on the HBR2 vessel head.

In the initial submittal on PTS susceptibility (dated June 29, 1984), CP&L presented the results of these efforts, which demonstrated that the lower circumferential weld was much less susceptible to radiation embrittlement than previously predicted and it would pass the PTS screening criteria with considerable margin. As an added conservatism, CP&L pioneered development and implementation of a program which provided a factor of 9 flux reduction at the lower weld by use of fuel assemblies containing stainless steel shielding at the lower weld elevation (Partial Length Shielded Assemblies).

At the time of that original submittal, CP&L lacked sufficient evidence to support the use of the surveillance weld chemistry to represent the upper circumferential weld in light of EPRI's conclusions questioning the identity of the surveillance weld. Therefore, CP&L used a "best estimate" chemistry as representative of the upper circumferential weld. Resolution of this issue was not crucial since the upper weld passed the screening criteria using either the surveillance weld chemistry or the best estimate chemistry. However, as analysis and flux reduction relieved the lower circumferential weld from concern, the controlling nature of the upper circumferential weld for PTS consideration, operating limits, and possible life extension was recognized. With this evolution, the identity of the HBR surveillance block became an important issue, and CP&L began an investigation into the surveillance weld identity.

That investigation produced a document trail that tracked the progress of the HBR2 surveillance weld from the welding process through to the final cutting of the weld block into the surveillance capsules and charpy specimens. The documentation clearly identified the welding process and weld materials used in its fabrication. Identification of specific HBR2 plate characteristics within the documentation enhanced the already strong creditability of these official records. The records established a very strong case for the originally claimed identity of the surveillance weld and firmly established certain chronological limitations with which previously speculated mix-up scenarios proved incompatible.

Due to the strength of this evidence CP&L could no longer support the EPRI and Westinghouse positions which questioned the identity of the surveillance weld. Therefore, our January 22, 1986, response to the final rule identified the surveillance weld chemistry as representative of the chemistry of the upper circumferential weld. This was a conservative action on CP&L's part since use of the alternative EPRI proposed chemistry would have resulted in a lower calculated PTS reference temperature (RT_{PTS}).

In a letter dated August 26, 1986, the NRC noted the inconsistency of this position with the previous submittal and the previous EPRI conclusions. That letter requested that CP&L to resolve the question of the surveillance weld identity and specifically address the apparent inconsistencies of the surveillance weld copper and nickel chemistries from those predicted by the EPRI study.

At a December 18, 1986, meeting with the NRC, EPRI, and Westinghouse, CP&L made a presentation which resolved both identity and inconsistency questions. A discussion of the major points and conclusions follows:

DISCUSSION

HBR SURVEILLANCE WELD TRACEABILITY

CP&L's investigation has produced a very complete set of official records which document the progress of the fabrication of the HBR2 surveillance capsule from the welding process at Combustion Engineering (CE) through the final cutting and machining of the surveillance capsules at Westinghouse. These records clearly document the weld procedures and materials used in fabrication of the surveillance weld. The records include:

- HBR2 plate material specification.
- Shop traveler documenting progress of weld in CE shop.
- Weld inspection record documenting weld materials and procedures used.
- Shipping records documenting shipment of weldment from CE to Westinghouse.
- Capsule and specimen fabrication drawings documenting processing of the surveillance weld block into capsules and test specimens.

The relationship of these documents to the HBR2 surveillance weld is demonstrated by identification of specific characteristics of the original HBR2 plate within the documents. These "tracer" characteristics (identified below) are either unique to the HBR2 plate or very unusual for plate used in vessel fabrication during the same time.

The tracer characteristics of HBR2 plate are:

- Vessel Plate Identification Numbers
  - W-10201-1
  - W-10201-3
- Vessel Plate "Low Nickel" Chemistry
  - Approximately 0.10% Ni
- Vessel Plate Steel Type
  - SA 302-A
- Vessel Plate "Unique" Thickness
  - 10.75 inches

The validity of each of the previously listed surveillance weld documents is supported by identification of at least two of the tracer characteristics within the document. The probability of any possible mix-up scenarios is extremely remote in light of the information recorded in these documents.

In addition, Westinghouse performed a chemical analysis on one of the broken HBR2 surveillance weld capsule specimens. The chemistry of the plate material in the heat affected zone sample confirmed the low nickel chemistry indicative of the Type 302-A steel used in the HBR2 vessel and surveillance weld. This combination of low nickel plate with a nickel addition weld on the same specimen is unique among surveillance specimens received by Westinghouse and effectively precludes the possibility of any mix-up of the capsules while at Westinghouse.

Westinghouse has reviewed the findings of this investigation and their conclusions concerning the HBR2 surveillance weld are quoted below:

> "From the Review of the records provided to Westinghouse by Combustion Engineering as a normal course of doing business during the fabrication of the H. B. Robinson Unit 2 reactor vessel and based on the manner in which Westinghouse monitors the surveillance capsule program materials from the day the materials are received through final assembly and shipment of the surveillance capsules, Westinghouse concludes that the H. B. Robinson Unit 2 surveillance material is representative of the H. B. Robinson Unit 2 reactor vessel. To reiterate as to the issue in question, the Combustion Engineering supplied surveillance weldment, Westinghouse concludes that this weldment is representative of the H. B. Robinson Unit 2 intermediate to upper shell course circumferential weld seam.
>
> Westinghouse's conclusions are based on the following observations and facts:
>
> 1. The uniqueness of the surveillance weldment thickness 10 3/4 inches.
>
> 2. The uniqueness of the chemical composition of the plate material from which the surveillance weldment was made (SA 302 Grade A - negligible nickel content) versus the composition plate material in the shop at the same time

period as the H. B. Robinson Unit 2 material (A533 Grade B Class 1 - approximately 0.5 weight percent nickel).

3. Documents and records establish a consistent and creditable basis for establishing that the surveillance program capsule weldment material is representative of the H. B. Robinson Unit 2 reactor vessel intermediate to upper shell course circumferential weld seam."

WELD CHEMISTRY INCONSISTENCY

The original EPRI conclusion questioning the identity of the HBR2 surveillance weld identity was based upon the observations that the nickel content of the HBR2 surveillance weld was significantly lower than that observed in other similar welds where the nickel was added by a "cold wire feed" process. Furthermore, the copper content of the surveillance weld was significantly higher than a statistically predicted maximum based upon measurements of a family of similar weld wires. Based upon these observations, the EPRI report concluded that the HBR2 surveillance weld was not a member of either of these groups and was, therefore, not fabricated with the materials and procedure claimed by the weld records. Although the copper and nickel inconsistencies combine to formulate the argument against the originally claimed surveillance weld identity, they are independent parameters of the weld and will be addressed separately in subsequent discussion.

NICKEL INCONSISTENCY

Most of the welds in the Robinson Vessel Program belong to a relatively small family of welds termed "Ni - 200 Addition" welds (fabricated in the 1965 to 1967 time frame). The nickel content of this particular type of weld is due almost entirely to the nickel provided via a separate pure nickel wire that was fed directly into the molten weld bead (cold wire feed). Since the general procedures for this type of weld identified a 1% target for the nickel additions, the EPRI report originally assumed that all such Ni - 200 Addition welds should exhibit similar nickel content at or around that value.

The EPRI Study observed that the average nickel content of all data available for Ni-200 Addition welds was approximately 1.1%. Since the measured nickel content of the Robinson surveillance weld was 0.66%, EPRI concluded that the HBR2 surveillance weld was probably not a member of this Ni-200 Addition family of welds.

However, CP&L's investigation has revealed that significant procedural differences existed between the HBR surveillance weld and the other Ni - 200 Addition welds used for comparison in the study. These procedural differences demonstrate that the H. B. Robinson Surveillance Weld, Upper Circumferential weld, and Head Torus to Dome weld comprise a subset within this family of Ni - 200 Addition welds which is defined by a unique welding process with substantially different welding parameters.

The three Robinson welds were fabricated using a single primary electrode feed in conjunction with the cold wire nickel feed. However, all other members of the Ni-200 comparison group were fabricated using a tandem primary electrode feed while retaining a single, cold wire, nickel feed. The differences between these tandem and single arc processes and the potential impact on resulting nickel content of the weld are demonstrated by a direct comparison of the detailed procedural welding parameters. The critical parameters of these welding processes are compared in the following table:

COMPARISON OF PROCEDURAL DIFFERENCES BETWEEN SINGLE & TANDEM WELDS

	Single Arc	Tandem Arc HBR Head Torus to Flange Weld	Tandem Arc Millstone Surveillance Weld
Number of Primary Arcs	1	2	2
Number of Ni Feed Wires	1	1	1
Amps	650	600/550	600/500
Travel	13 IPM	22 IPM	22 IPM
Primary Wire Feed Rate	Not Specified	Not Specified	Not Specified
Ni Wire Feed Rate	4 IPM	6 IPM	6 IPM
Procedurally Specified/Predicted Ni - Content	1.0%	1.29%	1.29%

As can be seen from this comparison, the critical welding parameters differ substantially between the single and tandem processes. Since these parameters establish the relative feed rates of the primary and pure nickel wire, it would be expected that the resulting nickel content may vary substantially between single and tandem arc welds. Perhaps the most important comparison is the predicted nickel content. This clearly shows that this single arc process was intended to produce substantially lower nickel content than the tandem arc process.

In practice these procedurally predicted nickel contents apparently were not achieved. The EPRI Report shows that the Millstone Surveillance Weld produced nickel ranging from .85 to 1.1% with an average of .98%. Samples from the HBR2 Head weld demonstrated nickel at .99%. This would indicate that these particular tandem arc parameters produced actual welds almost 25% lower in nickel than procedurally predicted. Although it would be inappropriate to expect the single arc welds to exhibit the same magnitude of variance from the prediction, this certainly indicates that a substantial overestimate could be expected.

Aside from the HBR2 Surveillance Weld there is an additional source of data for direct comparison of single arc weld chemistry. Previously, CP&L had removed samples from two locations on the Robinson head torus to dome weld which was one of the three welds identified in this single arc subset. This data was originally presented in a Westinghouse report entitled "Chemical Analysis of Reactor Vessel Head Torus-to-Dome Weld Samples from H. B. Robinson Unit No. 2" which was submitted with the June 29, 1984, CP&L submittal.

The relatively low nickel content of that single arc weld further supports the contention that the single arc welds produced significantly lower nickel content welds than the procedure predicted and also significantly lower than the tandem arc data used in the original comparison.

These findings provide a very logical explanation for the apparent inconsistency of the HBR2 surveillance weld nickel content with the other Ni-200 Addition welds used for comparison in the EPRI study. Furthermore, the fact that both the surveillance weld and the upper circumferential weld were produced within three weeks of each other using identical weld procedures establishes a crucial link between the welds which is essential to the applicability of the surveillance weld.

COPPER INCONSISTENCY

The EPRI study compiled a data base of copper values for weld produced from several heats of RACO 3 wire produced during the same time frame. Although some variability would be contributed by the different heats of bare wire, the data base primarily demonstrates the variability of the copper coating process in effect during this time frame.

This EPRI data base consists of 43 copper measurements (data entries) taken primarily from 10 surveillance welds. From statistical analysis of the copper content distribution of this data base, the EPRI report observed that the mean value for total copper content of this family of RACO 3 wires was approximately .19 percent. The statistically predicted maximum copper content of this family of RACO 3 wires was established as .26 percent (with a 98 percent confidence level). Since the surveillance weld copper content of .34 exceeded the predicted maximum, it was concluded that the weld was not made from a member of this family of RACO 3 wires.

It should be emphasized that the apparent copper inconsistency of the HBR2 surveillance weld is based strictly upon statistical evaluations. While the EPRI study itself recognizes that significant variability of copper may exist within the family of similar weld wires and even within samples of wire from the same heat, the data suggest that such variability would not be great enough to allow inclusion of the HBR2 surveillance weld as a member of this family of welds. Since the confidence level attributable to such statistical arguments is directly related to the size of the data base, an examination of that data base is appropriate.

As discussed during the meeting with the NRC, CP&L believes that the data contained in the B&W 1799 Report," B & W 177-FA Reactor Vessel Beltline Weld Chemistry Study," provides significant insight into the variability of copper coating on weld wire which has a direct impact upon the interpretation of the EPRI data base. Although data is from weld wires from suppliers other than Reid-Avery, it is assumed that the coating processes are basically similar among all suppliers. Therefore, it is believed that the weld characteristics observed from this data are also applicable to welds produced from other suppliers although the magnitude of the effects may be influenced by process variabilities among individual suppliers.

Appendix A of the B&W Report clearly demonstrates that significant copper coating variability may exist among samples taken from different coils of wire within the same heat.

The report also provides data on the through-weld variability of copper in both surveillance and actual vessel welds. The through-weld copper data demonstrates that surveillance welds exhibit a relatively constant through-weld variability which would appear to be characterized as a limited range of data scattered around a well-established mean value which remains relatively constant throughout the weld thickness. However, actual vessel welds display a comparatively wide copper variability through the depth of the weld. The variability of actual vessel welds would appear to be characterized by multiple layers which exhibit internal copper consistency within each layer, yet demonstrate that significant variability of the copper content can exist among the different layers.

These characteristic copper profiles can be explained by consideration of the number of coils used in the fabrication of each type of weld. The surveillance welds are very short welds probably fabricated from a single coil of wire. Therefore, the relative through-weld copper consistency can be interpreted as indicative of the relative consistency of the coating along a given coil. However, actual vessel welds are much longer and require several coils in their fabrication with each coil producing a layer of weld metal. When viewed from this perspective, the observed through-weld variability of copper in the actual vessel welds is quite compatible with the previous observations that the copper coating applied to each coil is relatively consistent along its length while significant coating variability can be exhibited between coils within the same heat of wire.

This observation would indicate that the individual coil represents a fundamental unit in consideration of copper variability within a heat of wire. Since all measurements from a single surveillance weld are actually multiple readings from the same individual coil, they are not independent representations of the variability within that heat. Therefore, they do not represent independent data points and should be averaged to produce one value representative of an individual coil within a family of variable coils.

When this approach is applied to the original 43 data points in the original EPRI data base the resulting data base is reduced to 13 independent entries representing 13 different coils. This data base can then be viewed as a very limited sampling of 13 coils from a total population of about 2,000 to 3,000 coils in the five heats used in the study. Although this sample size is probably sufficient to provide an indication of the mean copper value of the entire population, the confidence level of statistically predicted maximum copper values made from such a limited data base is greatly reduced and the probability that the HBR2 surveillance weld is a member of the data set becomes much greater. CP&L contends that the surveillance weld cannot be discredited as a member of this family of weld wires based upon statistical predictions made from such a limited data base. Furthermore, the surveillance weld copper content is considered conservative since it is apparently representative of the upper range of the variability within this family of RACO 3 weld wires.

This discussion has been presented in detail to EPRI and they have concurred with the conclusions concerning the appropriate size and the associated confidence level attributable to the data base and the conclusions that have been drawn from it.

CONCLUSION

The documentary evidence establishes an extremely creditable case supporting the originally claimed identity of the surveillance weld. Furthermore, the apparent weld chemistry inconsistencies which initially raised the question of the surveillance weld identity have now been adequately explained. Throughout the extensive investigation of weld chemistry and welding documentation, no evidence has been discovered which is in any way inconsistent with the originally claimed surveillance weld chemistry. Therefore, CP&L has concluded that the surveillance weld is indeed a single arc, Ni - 200 Addition weld process using RACO 3, Heat W5214 weld wire.

The details of this investigation have been presented to both EPRI and Westinghouse. Both have revised previous positions and are now in full agreement with our position supporting the originally claimed identity of the HBR2 surveillance weld. Both have expressed their support at our December 18, 1986, meeting with the NRC staff.

Furthermore, based upon the considerations that:

- Both the surveillance weld and upper circumferential weld were produced using identical weld procedures;

- The surveillance weld was produced just 3 weeks following completion of the upper circumferential weld;

- The surveillance weld was inherently intended to be characteristic of the upper circumferential weld and;

- The copper content of the surveillance weld is conservatively high in comparison to the probable copper content of the upper circumferential weld;

CP&L contends that the HBR2 surveillance weld is representative of the upper circumferential weld in the vessel.

Data from two valid surveillance capsules is available. Therefore, CP&L would be able to utilize this data to determine the Adjusted Nil Ductility Transition Reference Temperature and the charpy upper-shelf energy for the upper circumferential weld as allowed by section C.2 of the Draft Regulatory Guide 1.99, Rev. 2 when that Guide is issued in final form.

REVISIONS TO PTS SUBMITTAL

The results of this study and subsequent discussions with the NRC staff have some impact upon our January 22, 1986, response to the final PTS rule. CP&L initially used an overly conservative PTS calculation technique for the upper circumferential weld in the original submittal. Per discussion with the staff, the RT_{PTS} value has been recomputed using the alternate technique specified in the PTS Rule. The chemistry values used in this recalculation are those of the HBR2 surveillance block. This is the preferred method of establishing weld chemistry as specified in the second paragraph of Section E.3.1, Appendix E of the PTS Report (SECY 82-465). In this case, the surveillance weld satisfies the specified requirements of the weld metal qualification weld. As previously discussed, our investigation indicates that the average copper content of the surveillance weld at 0.34% falls on the high end of the expected variability for weld wires of this heat. Therefore, there is a very high probability that the average copper content of the actual upper circumferential vessel weld is significantly lower than 0.34%. The use of this copper value is therefore viewed as an additional conservatism in the calculation of PTS susceptibility of the upper circumferential weld.

Paragraph 7.1 in the PTS submittal has been revised to make use of the equation which yields the lower rather than higher RT_{PTS}, per 10 CFR 50.61.

7.0 RT_{PTS} Calculations

7.1 Upper Circumferential Weld

$$RT_{PTS} = I + M + [-10 + 470\ Cu + 350\ CuNi]f^{0.270}$$

where

$I = 56°F$

$M = 59°F$

$Cu = 0.34\%$

$Ni = 0.66\%$

$f = 1.76$

$$RT_{PTS} = -56 + 59 + [-10 + 470\ (0.34) + 350\ (0.34 \times 0.66)]\ 1.76^{0.270}$$

$$= 269°F$$

Finally, recognition of the procedural differences between single and tandem arc welds has demonstrated that our previous use of nickel data from a single arc weld on the HBR2 head torus to dome seam is not an appropriate representation of the tandem arc process used on the lower circumferential weld. A detailed investigation of tandem arc weld procedural variations and resulting nickel content would be necessary to establish the best estimate of how the specific parameters used in the lower circumferential weld fit into the EPRI data base of tandem arc Ni-200 welds. That data base exhibited a range of .98 to 1.26% nickel.

However, calculations have shown that a nickel content of 2.0% would be required before the lower weld would surpass the upper circumferential weld and become controlling for PTS consideration. Furthermore, a nickel content above 2.3% would be required before the lower weld would exceed the PTS screening criteria. Based on the fact that these nickel contents are significantly outside the range of the EPRI data base, it follows that the upper circumferential weld remains the controlling weld and that further evaluation of the lower circumferential weld is not required for PTS considerations.