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REPORT NC. NUREG/CR-4947, ORNL/TM-10459

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SUBJECT: ANALYSIS OF THE A302B AND A533B STANDARD REFERENCE MATERIALS IN SURVEILLANCE CAPSULES OF COMMERCIAL POWER REACTORS

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We apologize for the inconvenience.

Sincerely,

F. W. Stallmann

Enclosures

in the Pachur model; however, hyperbolic tangent fits were also tried and found to be virtually indistinguishable from the Pachur fits (see Tables 1 and 2). Individual fits are shown in Appendix A, and details are discussed in Appendix B.

The dependency of the NDT shift on the damage fluence, i.e., the trend curve, for the two materials needs to be determined next. The values proposed by the Revision 2 of Regulatory Guide 1.99[4] are quite adequate for this purpose. They are given by the formula

$$\Delta RT_{NDT} = [CF] \cdot f^{(0.28-0.10\ \log_{10} f)}$$

where [CF] is a "chemistry factor" which is given in tabular form, depending on copper and nickel content, and separately for base material and welds. The symbol f stands for fluence E > 1.0 MeV in 10^{19} n/cm^2. ΔRT_{NDT} is in degrees Fahrenheit at 30 ft-lb.

The investigation of other models, e.g., by R. Odette[5] (using data from Ref. 6) and D. Pachur,[2,3] is planned for the future. However, no substantial changes in the shape of the trend curve is expected for the other models.

The use of standard reference materials is based on the idea that anomalous conditions in regard to fluence, fluence rate, and irradiation temperature can be detected by correspondingly anomalous behavior of the reference material. The difficulty is that it is not easy to determine whether anomalous embrittlement is caused by the radiation environment or by problems inherent in the reference material. Such problems are

- uncertainties in the determination of the trend curve for the reference material,
- inhomogenuities in the reference material, and
- uncertainties in the determination of the NDT shift,

and need to be considered. Significant errors in the trend curve determination will show up as systematic biases. These biases may be either independent of the fluence, e.g., due to an incorrect chemistry factor, or fluence dependent, indicating errors in the fluence factor. Such systematic biases can never be completely separated from random errors but the relatively large number of data will guard against neglect of large inconsistencies with the trend curve model.

Change of material properties within the reference material is a serious problem. Tests made from different sets of specimens for the unirradiated material reveal considerable differences in the baseline NDT for the ASTM A302B plate as well as the three HSST plates (HSST01, HSST02, and HSST03). The test specimens used for the baseline of the A302B reference material (LT orientation) in surveillance capsules have a C_v, 30-ft-lb transition temperature of 34°F against the value of 15°F quoted in Ref. 7 and 29°F for the ORR-PSF experiment.[9] For the HSST02

If the deviations from the expected radiation damage exceed the uncertainties described above, anomalies in the capsule environment, i.e., fluence, fluence rate, or irradiation temperature must be suspected. Errors in the fluence determination which are large enough to significantly influence the damage prediction can be ruled out in most cases, perhaps with the exception of very low fluences. Dependency of radiation damage on fluence rate has been postulated by several authors, but the present investigation has not been able to either confirm or rule out such dependency. Whenever the radiation damage is either larger or smaller than expected, fluence rates are not significantly different from other capsules which behave normally. One exception is the irradiation in simulated surveillance capsules of the ORR-PSF experiment.[9] This leaves irradiation temperature as the most likely cause for variations in the damage for comparable fluence. Temperature monitors within the surveillance capsules give only the upper bound and, in case of melting, do not indicate whether any high temperature was transient or sustained.

It is a good indication that capsule anomalies are the cause for deviation from the expected radiation damage of the reference material, if the other materials in the capsules show similar deviations. For this reason, the radiation damage for all materials in a given capsule is investigated in this report; excluded were the heat-affected-zone materials and a few other test samples where the paucity of data points and large scatter prevented a reliable determination of the NDT shift. Also excluded were materials where the nickel content was not determined. Not all materials can be expected to fit equally well the Reg. Guide 1.99 model, and this is found to be the case. Thus, confirmatory data from other surveillance capsules or test reactor experiments are desirable to eliminate material-specific effects.

3. RESULTS

The chemistry for copper and nickel[14,15,16,17] and the chemistry factor according to Reg. Guide 1.99, Rev. 2, for the Standard Reference Materials are listed below.

Material	Cu (%)	Ni (%)	Chemistry factor
ASTM01	0.200	0.180	100.00
HSST01	0.180	0.660	136.10
HSST02	0.170	0.640	128.00
HSST03	0.120	0.560	82.20

3.1 A302B (ASTM) REFERENCE MATERIAL

The results from 26 capsules in nine (Westinghouse) plants have been investigated. The capsules in the H.B. Robinson Reactor contain specimens cut in the TL (weak) direction; all others are cut in the LT (strong) direction. Also included for comparison purposes are the results of the PSF and Blind Test experiments[9] for this material (see Fig. 1). The baseline values for these specimens differ somewhat from that of the set assigned to the surveillance capsules, but the difference is within uncertainties for the Pachur fit. A large number of irradiations have also been performed previously on the specimen from the same plate and reported in Ref. 7. Since Ref. 7 contains no raw data and only sketchy information concerning dosimetry, irradiation temperature, and irradiation time, no use is made of these data.

Compared to the prediction of Reg. Guide 1.99, a bias of -6% is detected for the reference material, i.e., the measured NDT shifts are on the average 6% larger than the Reg. Guide values. A similar bias, namely -7%, is found if the data from all materials of all capsules containing the A302B reference material are included. This suggests that the bias is not related to the reference materials but to the plants and capsules. A possible explanation could be that the irradiation temperature in the capsules of these plant is, on the average, lower than in the sample from which the Reg. Guide 1.99 trend curve was determined. No melting of the thermal monitors was reported for all the affected capsules and, while this is no positive proof of lower than normal temperature, it cannot be ruled out. Also, a few older plants were operated conservatively with operating temperatures of less than 500°F.*

It is much more difficult to determine an abnormal capsule environment for individual capsules. While, in general, underprediction of radiation damage for the reference material goes hand-in-hand with underprediction for companion materials in the same capsules, there are many exceptions to this rule. This may be due to

- deviation of the trend curve for plant-specific material from Reg. Guide 1.99,
- uncertainties in the chemistry of the plant-specific material,
- differences in temperature and fluence within the capsule, and
- sample-to-sample variations in both plant-specific and reference materials.

Thus, clear-cut correlations between the behavior of the reference and plant-specific materials can be found only in extreme cases and even these are difficult to quantify. However, findings of large deviations from Reg. Guide 1.99 trend curve are useful as warning flags that invite further scrutiny.

The test reactor data from the ORR-PSF experiment follow, in general, the same trend curve as the surveillance data. However, the specimens in the high-fluence, high-fluence-rate SSC2 capsule show larger than predicted embrittlement and slightly less than predicted damage for the wall capsules at 1/4 and 1/2 thickness. This appears to be a dose-rate effect; higher dose rates are expected to lead to higher values for the NDT shift at saturation, i.e., high fluences. Possible dose-rate effects at lower fluences are not large enough to be detectable with the means employed here.

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*Private communication, Stan Anderson.

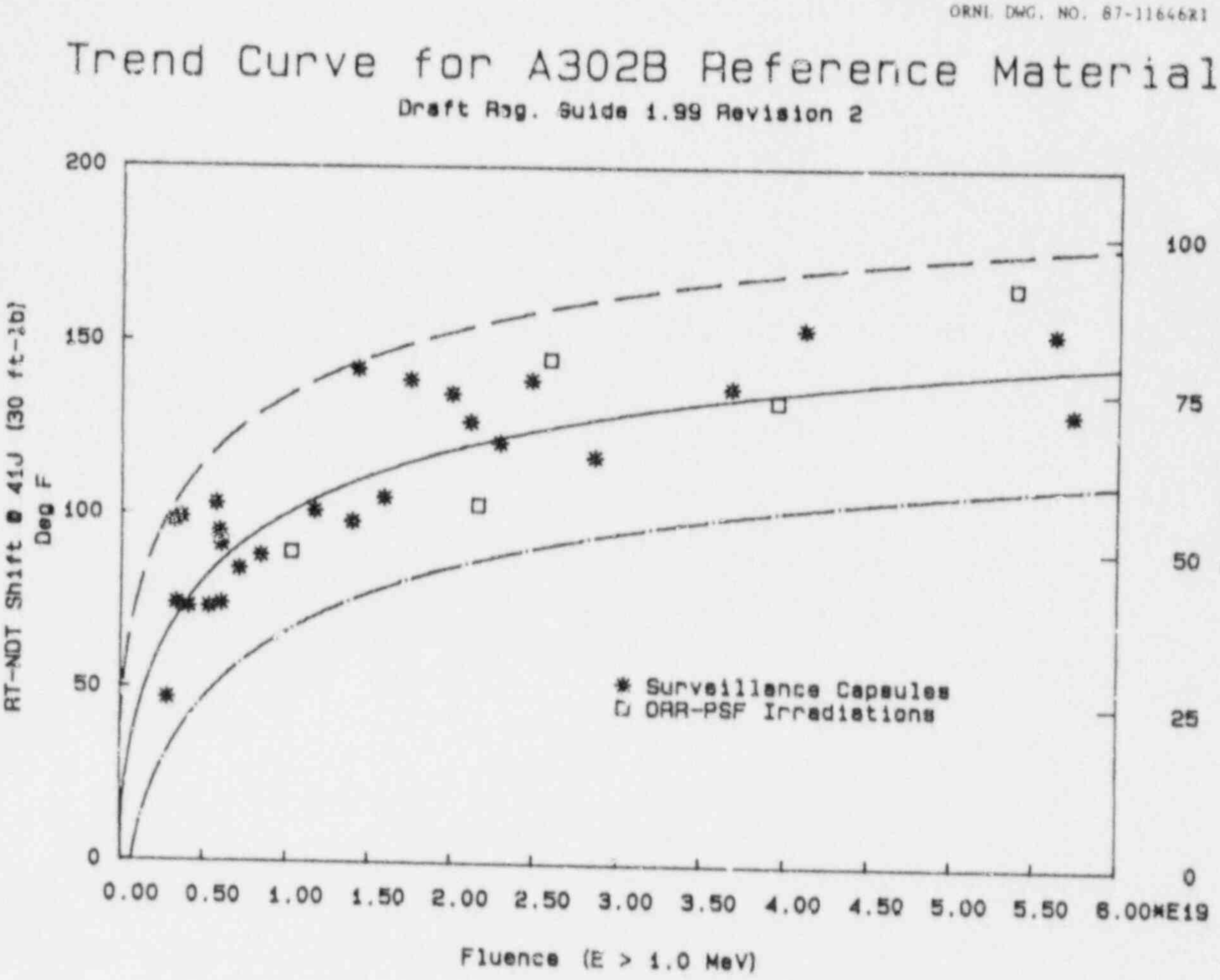

Fig. 1. Embrittlement of the A302B reference material relative to the draft Reg. Guide 1.99, Revision 2. The upper and lower curves are the 34°F uncertainty bounds (2σ) specified by Reg. Guide 1.99.

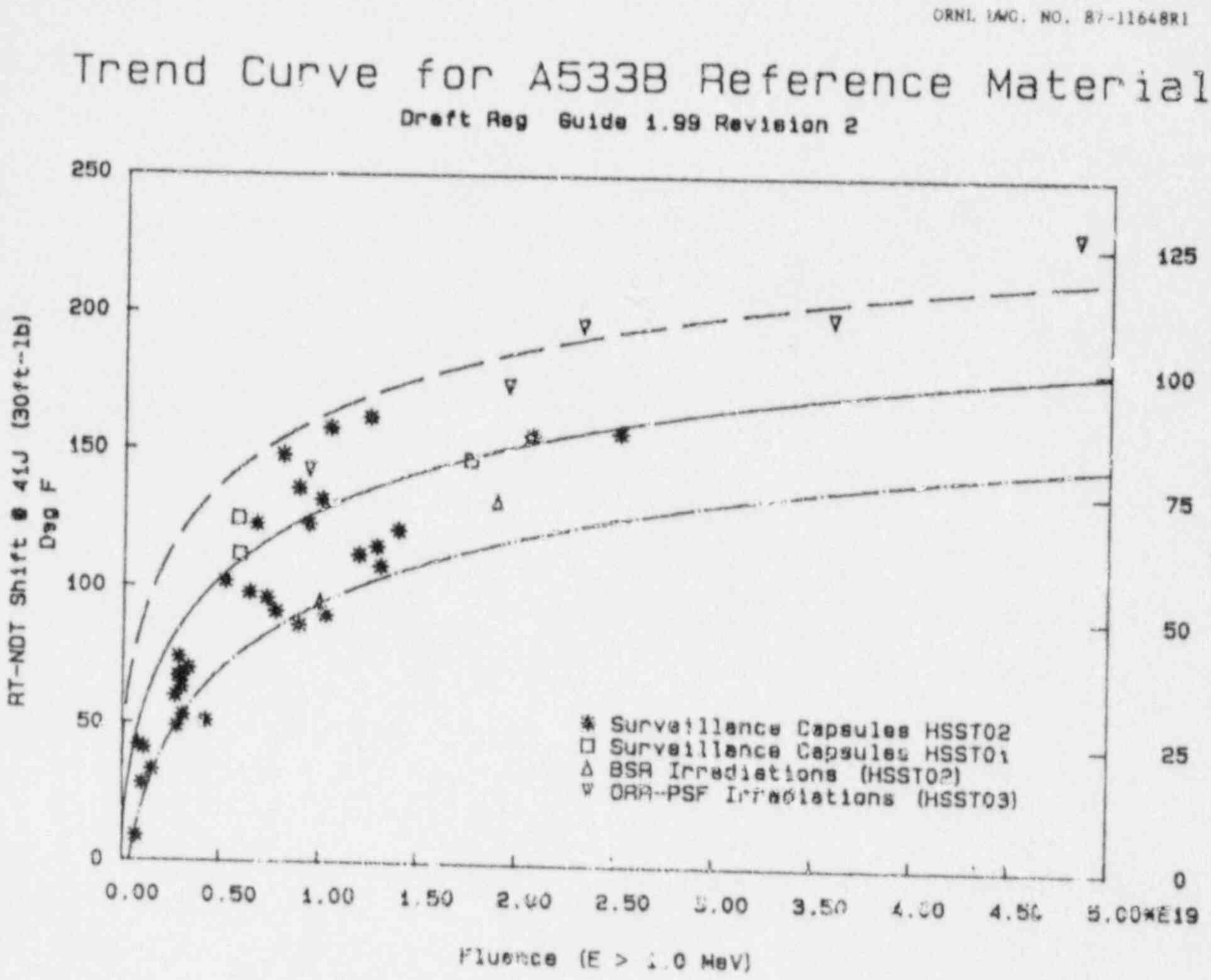

Fig. 2. Embrittlement of the A533B reference material relative to the draft Reg. Guide 1.99, Revision 2. The values for HSST01 and HSST03 plates are adjusted relative to HSST02 plate to account for differences in chemistry. The upper and lower curves are the 34°F uncertainty bounds (2σ) specified by Reg. Guide 1.99.

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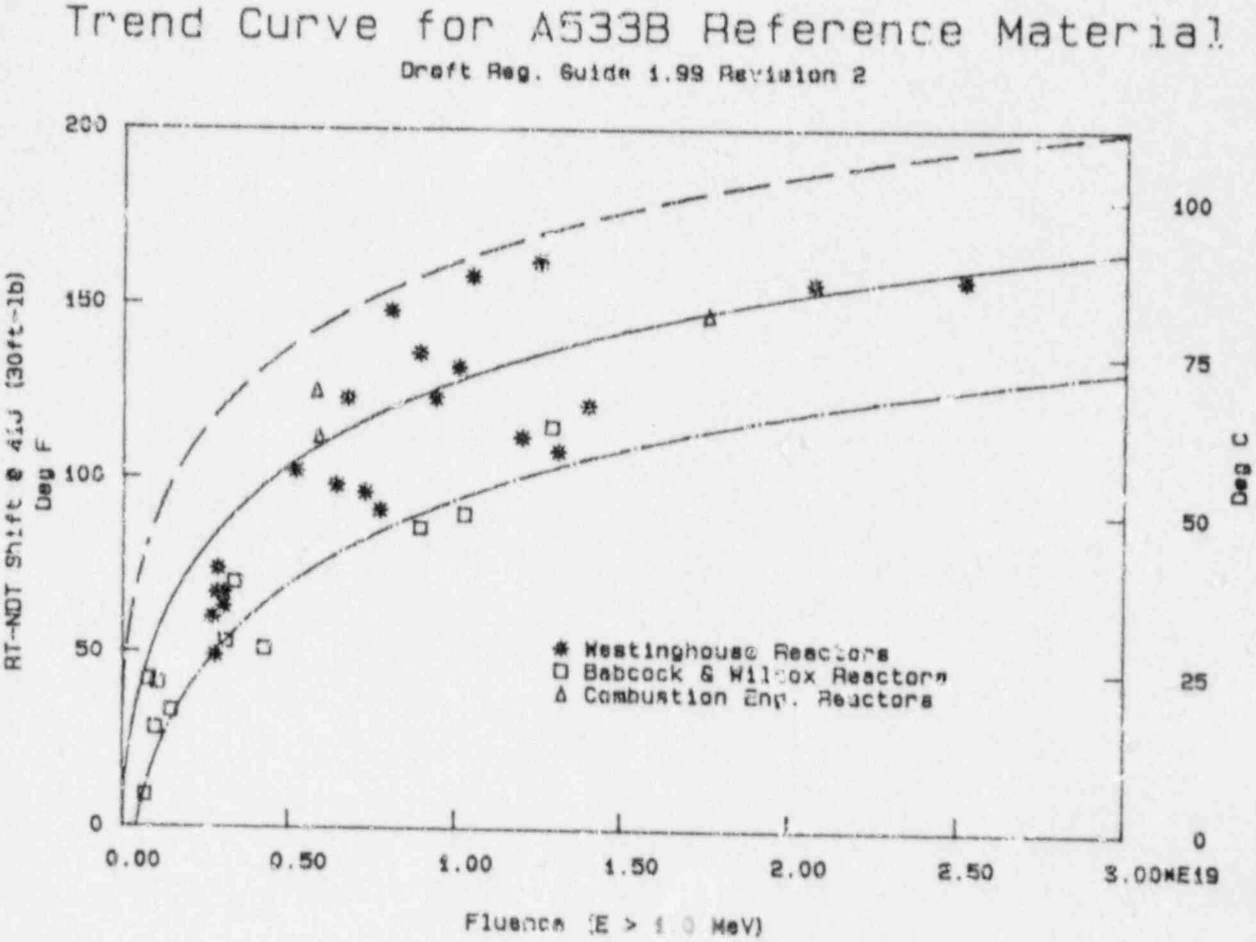

Fig. 3. Significant bias toward overprediction of the Babcock & Wilcox surveillance capsules. No bias is found for Westinghouse or Combustion Engineering capsules although the scatter is large. The upper and lower curves are the 34°F uncertainty bounds (2σ) specified by Reg. Guide 1.99. Values for the Combustion Engineering reactors are adjusted to account for the use of HSST01 plates.

14. S. E. Yanichko, Analysis of Capsule D from the Connecticut Yankee Reactor Vessel Radiation Surveillance Program, WCAP-10236, Westinghouse Electric Corporation, Pittsburgh, PA, January 1983.

15. J. R. Hawthorne, "Postirradiation Dynamic Tear and Charpy-V Performance of 12-in. Thick A533-B Steel Plates and Weld Metal," Nucl. Eng. Design 17 116-130, 1971.

16. A. L. Lowe, Jr., Analysis of Capsule AN1-A from Arkansas Power & Light Company Arkansas Nuclear One - Unit 1, Reactor Vessel Material Surveillance Program, BAW-1836, Babcock & Wilcox Company, Lynchburg, VA, July 1984.

17. J. R. Hawthorne, Light Water Reactor Pressure Vessel Surveillance Improvement Program. Postirradiation Notch Ductility and Tensile Strength Determinations for PSF Simulated Surveillance and Through-Wall Specimen Capsules, NUREG/CR-3295, MEA-2017, Vol. 2, U.S. Nuclear Regulatory Commission, Washington, DC, April 1984.