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Memorandum:

To: Mr. M. Bender, ACRS Ad Hoc Metal Components Subgroup.

From: W. R. Gall, Subgroup Consultant,
P.O. Box 334, Oak Ridge, TN 37830.

Subject: Comments on Report, "Pressurized Thermal Shock (PTS) in Nuclear Power Plant Reactor Vessels," Draft 3.

These comments on the proposed report are based primarily on the toughness requirements of Sections III and XI of the ASME Boiler and Pressure Vessel Code and on the effects of chemical composition on the radiation embrittlement of the materials.

The ASME Code and Appendix G to 10CFR50 include conservative requirements for toughness of materials used in nuclear equipment. The Code provides limits for four levels of service conditions to which the equipment may be subjected during operation. Level A and level B limits apply for normal operation and for unusual events which would not result in damage requiring repair. Those limits are generally the most conservative in the Code. Level C and level D limits apply to consideration of events which may produce some permanent effects requiring shutdown, inspection, and repair or removal. These limits are, of course, less conservative than those for levels A and B.

The toughness limits for levels A and B include extensive safety margins in the postulated flaw sizes and in the determination of K_I. Those limits are likely to be exceeded during an extreme overcooling event, especially if it occurs after several years of full power operation. There is also a tendency to introduce additional conservatism in the estimation of the shift of RT_{NDT}, which is not covered by the Code rules. Therefore, in considering these events, it may be necessary to reduce some of the margins of conservatism which are included in the limits for levels A and B for determining K_I and in the methods for determination of the increase of RT_{NDT}, by using the most realistic data that is available. In particular, the determinations of initial RT_{NDT} and toughness should be based on actual initial toughness tests which were performed on materials used in vessels constructed prior to the introduction of Appendix G in its present form, even though the toughness requirements at the time of construction differed from those currently in effect. From the results of those tests and of subsequent tests of surveillance specimens for the particular vessel, it should be possible to establish accurate values of initial toughness and RT_{NDT}.

The following comments and suggestions are related to specific contents of the report.

Maintaining the inner surface of the vessel wall above the "upper shelf" temperature, as suggested on page 3, may not be practical during

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some PTS events. In considering those cases it is necessary to verify the safety of the vessel by use of fracture mechanics methods.

On page 7, the parenthetical statement that the effect of fluence is assumed to be linear should be deleted.

It may be noted that the effect of nickel in the radiation embrittlement of steel has been taken into account, and apparently verified, in the analysis of surveillance tests performed for NRC. However, judging by the proposed revision of the equation for RT_{NDT} shift, the effect of copper still dominates.

The discussion of correlations of K_{Ic} with Charpy impact measurements, on page 8, is not clear. Accumulated data on K_{Ic}, K_{Ia}, and K_{Id} have been plotted against relative temperature, $(T - RT_{NDT})$, and lower bound curves established, below which values of K_I may be considered to be safe. The maximum values to which these curves go is 200 ksi$\sqrt{in}$, The shift of the Charpy V-notch transition curve due to exposure to fast neutron fluence is measured at the 30 or 50 ft-lb level and that temperature shift is added to the initial RT_{NDT} to obtain the post-irradiation value of RT_{NDT}. Then the K_{Ic} and K_{Ia} curves may be entered at $T - RT_{NDT}$ to determine the limiting K_I values for crack initiation and arrest at any temperature, T. For older vessels, one of the problems with this procedure is determination of the initial value of RT_{NDT}. However, since the materials used in all reactor vessels were required to be tested for Charpy impact properties, rational methods can be devised for estimating initial RT_{NDT} and toughness. In most of those cases the requirement was that 3 Charpy V-notch specimens tested at a temperature 60°F below the hydrotest temperature show an average of 30 ft-lbs with no specimen lower than 25 ft-lbs. Alternatively, drop-weight tests were conducted to establish that the NDT of the material was below a temperature of 60°F below the hydrotest temperature.

With reference to the effect of neutron attenuation through the vessel wall as discussed on page 9, several reports have included calculations of this effect. Fluence is reduced almost 50% in the first 2 inches of the vessel wall, and in 8 inches the reduction is 95% *. It was recommended by Steele and Watson* that the fluence exposure at $\frac{1}{4}$T be used for establishing radiation effects in preference to the exposure at the inner vessel wall surface. Especially for establishing the K_{Ia} limit, the effect of attenuation should be taken into account, because the K_{Ia} limits tend to occur at higher temperatures relative to RT_{NDT}.

Referring to the discussion of the effect of cladding, the true stress relationship between cladding and base metel at the interface is dependent upon the temperature history of the composite material. It seems more likely that under normal operating conditions the cladding

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*Steele, L. E. and Watson, H. E., "Interpreting the Structural Significance of Time-Dependent Embrittlement Phenomena to Nuclear Reactor Pressure Vessel Integrity", Journal of Materials, JMLSA, Vol. 7, No. 2, June 1972, pp. 178-187.

tends to be in compression and to apply a tensile load to the base material. When the fluid is cooled, as in an overcooling event, the cladding temperature drops below that of the base material. Whether this would reduce the tensile load on the base material or not depends on the magnitudes of the respective conditions. In general, the cladding should tend to reduce the neutron fluence incident on the ferritic base material and also to reduce the rate of cooling of it. However slight, these would seem to be beneficial effects.

Acceptance standards for nondestructive examination of welds and of base materials in Section III and in Section XI of the ASME Code are much smaller than the flaw size on which Section III toughness are based. The requirements in Appendix G of Section III for calculation of K_I are based on a postulated flaw depth of $\frac{1}{4}$T and length of $1\frac{1}{2}$T. The acceptance standards for radiographic and liquid penetrant, or magnetic particle, examinations allows no cracks, and limits other indications to a maximum length of 3/4 in. Section XI preservice examination acceptance standards limit depth to a maximum of 3.5% of thickness, and the maximum length permitted is 40% of the thickness only if the depth does not exceed 2% of thickness. The method for detecting these flaws in Section XI is ultrasonic examination.

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