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Draft R.G. MS501-4

Sandia National Laboratories
Albuquerque, New Mexico 87185

September 29, 1986

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51FR23613
86-5

Mr. H. Graves
Rules and Procedures Branch
DRR ADM
U. S. Nuclear Regulatory Commission
Washington, DC 20555

Dear Mr. Graves:

Attached are our comments concerning the Draft Regulatory Guide entitled "Fracture Toughness Criteria for Ferritic Steel Shipping Containers with a Wall Thickness Greater Than 4 Inches (0.1m)."

Sincerely,

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Physical Metallurgy Division 1832

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Transportation Systems Technology
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KBS:6322:mm/6031

Attachments

Copy to:
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COMMENTS ON THE DRAFT REGULATORY GIDE

"Fracture Toughness Criteria for Ferritic Steel Shipping Containers with a Wall Thickness Greater Than 4 Inches (0.1m)"

Sandia has reviewed the Draft Regulatory Guide and would like to offer some technical comments which may assist the NRC in developing the final document. The comments fall into three general areas of concern as follows:

1. Lack of adequate supporting evidence for the use of NDTT as a proper quality assurance parameter for fracture prevention of thick-walled shipping containers.

2. Assumption that design variables (including impact mitigation devices) have no effect on shipping container stresses.

3. Extrapolation of the "Pellini Curve" to regions outside its limits of applicability.

These three technically based concerns are discussed in detail below.

1. The NDT temperatures for materials listed in the Draft Regulatory Guide have not been sufficiently well documented in order to assume that they are applicable to all locations in all heats.

   The NDTT (Nil Ductility Transition Temperature) criteria, which are acceptable to NRC staff, are listed in Table 2 for three materials: SA-508-4A, SA-508-4B, AND SA-350-LF3 (note that this material is incorrectly identified in the Draft Regulatory Guide as SA-350-4B). These materials derive their high level of toughness and low NDT temperature by controlling the grain size and the phases which are present along with their distribution.

   Grain size is controlled primarily by the hot forging and subsequent heat treatment of the material. Without a uniform through-wall deformation of these alloys, the desired fine grain size cannot be maintained across heavy sections. The ASTM specification for Class 508 pressure vessel steel indicates that this forged material must be mechanically hot worked by equipment of sufficient capacity to "work the metal throughout its section." There has been no demonstration that large--that is, greater than 40 to 50 tons--vessels with finished wall thickness in the 14- to 20-inch range can be forged with the requisite hot work uniformly distributed through the wall. Further and more importantly, it must be recognized that the microstructure of thick-walled vessels will not be uniform across the cross section. This fact is an inescapable consequence of the nature of the martensitic phase transformation in ferritic steels and its dependence upon the local cooling rate. Heavy-walled forgings of greater than about 6 to 8 inches, of either SA-350 or SA-508 cannot be cooled quickly enough to produce martensite through the entire cross section. A different microstructure, specifically pearlite, will be formed in the center of the wall, and this phase combination (of lamellar carbide and ferrite) will not have as low and NDT temperature (or as high a toughness) as the optimized quenched and tempered martensitic phase.

The temperatures reported in Table 2 as being acceptable to NRC staff are presented without supporting documentation as to the size, exact chemistry, and treatment of the forgings or the number, location, and orientation of the test specimens. (It may, also, be noted that accuracy of measuring the NDTT of a material by the ASTM E-208 is ± 5C; thus the number of significant figures reported in Table 2 of the Draft Regulatory Guide is misleading as to the accuracy of the entire method.) The NUREG/CR-3826 report of M. W. Schwartz shows only one reference for each of the NDTTs reported. For the reported NDTTs to be considered as being "worst case" or even "typical," additional extensive information on heat-to-heat variations of these alloys must be gathered. In addition, information must be documented about the variation of the microstructure and NDTT across thick-walled sections.

A change in microstructure across a thick-walled forging is inevitable and must be properly accounted for in the methodology which assures that brittle fracture will not occur. These microstructural variations have not been considered in the criteria presented in the Draft Regulatory Guide.

2. The assumption of yield strength levels of applied stress is overly restrictive.

The Draft Regulatory Guide indicates that stress levels equal to the dynamic yield strength must be assumed in applying either the two crack arrest criteria or the fracture initiation criterion. Such a position entirely discounts the demonstrated capability of impact limiters in reducing the applied stress levels during accident type loading conditions. Credit should be allowed (with respect to brittle fracture resistance) for systems which can conclusively demonstrate effective stress limitation.

It is, also, important to discuss the nature of the stresses which result from the accident type loading conditions. Scalar stress representations, such as the von Mises equivalent stress or Tresca maximum shear stress ("stress intensity" defined by ASME and found in the NRC Reg. Guide 7.6), are useful in addressing yield criteria, not brittle fracture. The tensile components of the stress are important for addressing the potential for brittle fracture. Most accident type loading conditions result in stress fields that are dominantly compressive. Compressive stresses are not of primary concern for the prevention of brittle fracture. Therefore, effort at prevention of brittle fracture should be focused on loadings which can lead to the development of tensile stress fields and not solely on events which produce maximum scalar levels of (compressive + tensile) stress.

3. The application of the Pellini Reference Curve Crack Arrest Methodology (and its modifications) is inappropriate.

Four approaches are identified in the Draft Regulatory Guide, which can be used to establish the toughness criteria to evaluate ferritic steel containment vessels with wall thickness greater than 4 inches (0.1 m). Two of these approaches are crack arrest criteria which are based upon extrapolations of fracture toughness reference curves developed by Pellini. It should first be noted that the Pellini fracture toughness reference curve (crack arrest) approach was originally developed for a very different application which does not overlap the regime covered by shipping containers with wall thicknesses of greater than 4 inches. Arbitrarily forcing the Pellini approach to cover very thick-walled vessels is inappropriate.

The Pellini reference curve approach (and the modifications listed as Approaches 1 and 2) assumes the presence of through-wall flaws. Flaw sizes (dimensions) are consequently scaled with the wall thickness. While this assumption might be acceptable for situations where thickness is limited (certainly no more than 4 inches), it becomes intractable when wall dimensions are greater. As the flaw size becomes greater, a higher level of fracture toughness is required; this is accomplished (in the Pellini reference curve approach) by requiring a lower NDTT. There is no consideration given when applying this approach to thick-walled vessels that such flaws may be much larger (by an order of magnitude or more) than the detectability limit for conventional NDE (nondestructive examination) methods. Further, for thick-walled vessels the Pellini reference curve approach (without modification) dictates such low NDTTs that essentially all ferritic steels are eliminated (indeed, pushed to an extreme). This approach can dictate NDTTs below absolute zero; thus there is a range of wall thicknesses above which the original Pellini reference curve method is inapplicable. The Pellini reference curve approach further suggests that fracture toughness increases continuously with temperature for ferritic steels (an assumption which is not true).

M. W. Schwartz in NUREG/CR-3826, "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Greater Than 4 Inches Thick," has suggested two modifications to the Pellini reference curve approach in order to apply it to thick-walled vessels. The shortcomings of the Pellini reference curve approach are tacitly acknowledged in these modifications. The modifications are imposed in order to limit the NDTT of the steel to a reasonable temperature. The mathematical extrapolations of the fracture toughness reference curve are, however, not rigorously based on physically measured behavior. Their use is, therefore, highly arbitrary and is imposed solely in order to "force fit" this reference curve approach onto thick-walled vessels. Assurance against brittle fracture must be soundly based on actual material behavior and not on extrapolations outside of the range of measured materials properties.

Conclusions

In order to demonstrate that brittle fracture will not occur in shipping casks, two materials characteristics must be considered. First, the material must be shown to display upper shelf--that is, "ductile"--behavior for all use conditions (including loading rate and lowest service temperature). Secondly, the level of the upper shelf fracture toughness must be shown to be adequate. Demonstration of adequate toughness is intimately connected with three distinct parameters. These are: 1) the fracture toughness of the material (to be measured at the appropriate location, loading rate, and temperature); 2) the most severe flaw that can be present (the largest flaw in the worst location and orientation that can be missed by the prescribed NDE methods); and 3) the most severe loading (the maximum tensile stress generated by the "hypothetical accident conditions" determined by analysis or testing). A fracture mechanics methodology has been developed to directly confront this problem and such "state-of-the-art" engineering capabilities should be applied to the licensing of shipping containers. Sandia recommends that transport cask material and design structural qualification be based on the fracture mechanics approach which links the three governing parameters of brittle fracture (material fracture toughness properties, design tensile stresses, and allowable flaw size) together. Basing the qualification on an inappropriate material property test will provide an overly conservative approach to material qualification. However, the NDT testing recommended does not provide sufficient background information to be transferable to thick-walled sections, and it does not address the design factors (tensile stress and flaw size) which affect brittle fracture.

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