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Regulatory Publications Branch, DFIPS
Office of Administration
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Attention Mr. W. E. Campbell, Jr.

Gentlemen:

Subject: Comments on the Draft Regulatory Guides, Task DG-7001 and Task DG-7002

Ref. 1: Task DG-7001, "Fracture Toughness Criteria for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of Four Inches (0.1m)"

Ref. 2: Task DG-7002, "Fracture Toughness Criteria for Ferritic Steel Shipping Containment Vessels with a Wall Thickness Greater Than Four Inches Thick (0.1m)"

The content of this letter will be divided into technical comments and general comments. In general, the comments will apply to Reference #2.

Technical Comments:

1. The NDT temperatures for the materials listed in Reference #2 have not been sufficiently documented to assure that they are applicable to all locations in all heats.

The NDTT criteria which are acceptable to NRC staff are listed in Table 2 of Ref. 2 for three materials: SA-508-4a, SA-508-4b and SA-350-LF3. These materials derive their high level of toughness and low NDT temperature by controlling the grain size and the phases which are present and 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 vessels with finished wall thicknesses greater than about 8" 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

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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. This phase combination of lamellar carbide and ferrite will not have as low an NDT temperature (or as high a toughness) as the optimized quenched and tempered martensitic phase.

The NDT 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. The NUREG/CR-3826 report shows only one reference for each of the NDTTs reported. For the reported NDTTs to be considered as being "worst case", or even "typical", detailed information on heat-to-heat variations of these alloys must be gathered; including information about the variation of the microstructure and NDTT across the thick walled sections. In addition, the NDT temperatures listed in Table 2 are reported in CR-3826 as mean values. Considering the magnitude of the standard deviations listed for the NDTT values, attempting to correlate a given level of toughness to mean NDT value is inexact at best.

In order to assess these concerns, Sandia sponsored NDT and Charpy impact testing at Texas A&M. The material which was evaluated was 8" and 12" thick forgings of SA-508-4a,b and SA-350-LF3. Table 1 shows the absolute result of the NDT testing on the three materials. SA-508-4a,b both meet the NDT values established in Reference 2. However, the NDT of -50 C for the SA-350-LF3 is significantly above the -120 C established for SA-350-LF3 in Ref. 2.

Additionally, it is helpful to evaluate the Charpy data. Figs. 1-6 show the absorbed energy vs. temperature plots for the three materials. The very low Charpy values at temperatures above the measured NDTT indicate possible brittle behavior. For example, Plane A of the SA-508-4a in Fig. 1 shows absorbed energy values of approximately 15 ft.-lbs. up to -90 C. By specifying only NDT values, other important aspects of materials behavior such as Charpy impact, are neglected.

The ASME Boiler and Pressure Vessel Code, Section III, Subsection NB-2300 imposes the Drop Weight Test to establish the NDT. However, it further requires that at temperatures at 60 F above the NDT, Charpy specimens exhibit 35 mils of lateral expansion and a minimum of 50 ft.-lbs. of absorbed energy. If these conditions cannot be met, a new NDT is established at a temperature of 60 F below the temperature at which the conditions can be met. According to the ASME criterion, it is likely that the design NDT temperature for SA-508-4a would be significantly above the measured NDT value (see Figs. 1,2). Again, using Plane A in Fig. 1 as an example, 50 ft.-lbs. occurs at -55 F. Subtracting 60 F from this value gives a design NDT of -115 F. The approved NDT temperature for this material in Ref. 2 is -150 F. Therefore, in using an ASME approach, SA-508-4a [illegible] the criterion set forth in Ref. 2.

2. The assumption of [illegible] s of applied stress is overly restrictive.

Ref. 2 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 the Tresca maximum shear stress ("stress intensity" defined by ASME and found in the NRC Reg. Guide 7.6) are useful in addressing yield criteria, but 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 those events which can lead to the development of tensile stress fields and not solely on events which produce maximum levels of a scalar representation of stress.

3. The application of the Pellini reference curve crack arrest methodology is inappropriate.

Four approaches are identified in the Ref. 2, which were evaluated for use in establishing the toughness criteria that can be used to evaluate ferritic steel containment vessels with wall thicknesses grater than 4 inches (0.1m). The approach recommended in Ref. 2 is the crack arrest criterion which is based on 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 greater than 4 inches. Arbitrarily forcing the Pellini approach, with no verification (through testing) of its application to transport cask design, can lead to an inappropriate conclusion. The work at Texas A&M demonstrates that a mathematical extrapolation of data, and conclusions drawn from such an extrapolation, must be backed up by test data.

The Pellini reference curve approach 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, it becomes intractable as wall dimensions increase. 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 a order of magnitude or more), than the detectability limit for conventional NDE method. Further, for thick walled vessels, the Pellini reference curve approach dictates such low NDTTs, that most ferritic steels are eliminated. Indeed, even SA-350-LF3 should not be included in Ref. 2 using Pellini criteria since it does not meet the established NDT value. Additionally, by focusing the entire approach on the NDT, Ref. 2 neglects the important Charpy behavior of the material. This is not to say that the material may be unsafe for the application; but rather, underscores the excessive constraints imposed by a Pellini approach for this application. These three ferritic steels (SA-508-4a,b & SA-350-LF3) have been used successfully in the nuclear field for many years.

It is also interesting to note that NUREG/CR-3826 (from which Ref. 2 is based) recommends using a fracture initiation approach over the fracture arrest approach. CR-3826 shows that, as wall thickness increases, the fracture initiation approach can be more conservative than fracture arrest, based on limit state probability.

General Comments:

1. Ref. 1 allows for a full-scale drop test as an alternative acceptance criteria. Ref. 2 should also allow a full-scale drop test as an alternative acceptance criteria. Full-scale drop testing was recommended as an acceptable alternative in NUREG/CR-3826.

2. A design methodology should be adopted which has the latitude to evaluate a general class of materials based on sound engineering principles. The draft Reg. Guides use a correlative approach (NDTT to fracture toughness) which results in restricting the materials which can be considered and forces an extremely high degree of conservatism on the material. No allowance is provided for implementing a complete design approach, which would include impact limiters (or other features to reduce stresses) and inspection (demonstrating that a proposed NDE procedure is capable of detecting flaws with an applied factor of safety).

A linear-elastic fracture mechanics LEFM approach can be used directly in a design application. A critical flaw size can be calculated based on the material's fracture toughness (the material property which indicates resistance to crack initiation), calculated stresses and NDE capabilities. Factors of safety can be applied to one or a combination of these three design parameters. This approach allows the consideration of a broad range of materials and uses a sound engineering basis for its application.

3. There is a significant amount of work both in the U. S. and internationally which indicates that an LEFM approach is a workable design methodology for this application. There is a current effort at the IAEA to develop a fracture toughness acceptance criteria based on LEFM. This effort was proposed at PATRAM '89 (1). Also, the ASME-NUPACK committee has been developing fracture toughness criteria which incorporates LEFM principles. This work is consistent with ASME Section III, Appendix G and ASME Section XI, Appendix A. We would recommend delaying the formal implementation of these draft Reg. Guides until such time as the IAEA and ASME efforts produce criteria which have the backing of the international technical community. Ideally, NRC support in these endeavors would help produce a standard criteria which would have the support of the regulatory as well as the technical community.

4. With regard to ASME-NUPACK, the NRC has recommended that only materials currently listed in Section III of the ASME Code be used for structural

components in cask applications. This recommendation excludes the option of a Code Case Inquiry to incorporate new materials into Section III. One material listed in Ref. 2 as acceptable to NRC for this application, SA-508-4b, is not included in Section III.

SUMMARY:

We recommend delaying the formal implementation of these draft reg. guides until such time as the IAEA and ASME efforts produce criteria which have the backing of the international technical community. Ideally, NRC support in these endeavors would help produce a standard criteria which would have the support of the regulatory as well as the technical community.

Yours truly,

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REFERENCE

1. Sorenson, K. B., Salzbrenner, R., Nickell, R. E.; "A Proposal for International Brittle Fracture Acceptance Criterion for Nuclear Transport Cask Application", The Packaging and Transportation of Radioactive Materials, PATRAM '89, June, 1989, Washington, D. C.

KBS:6322:0001
Attachments

Copy to:

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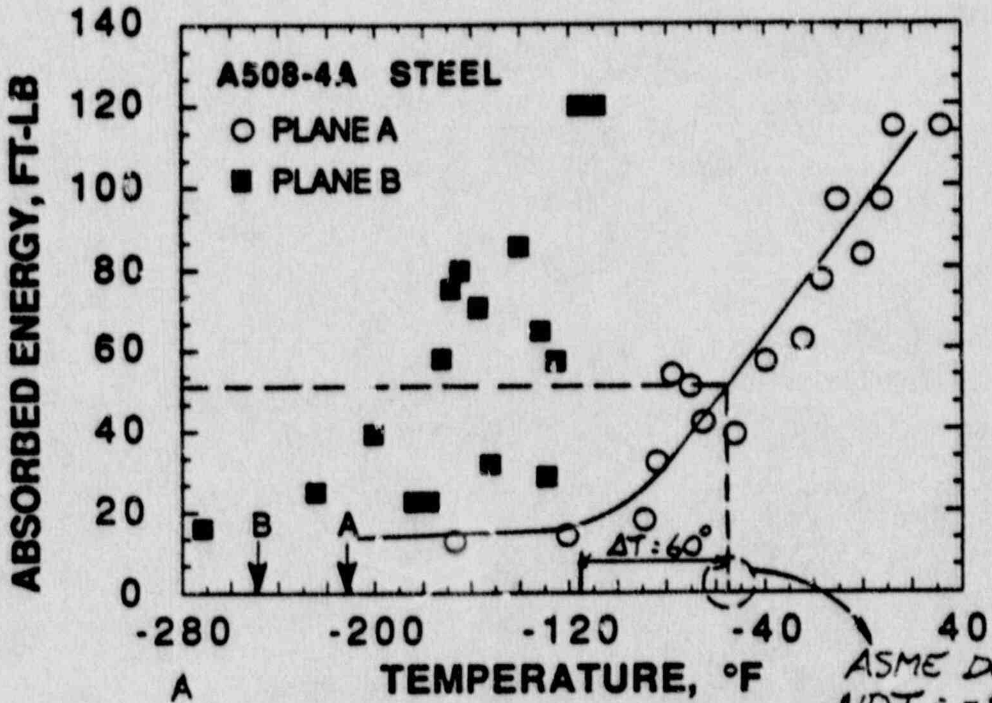
TABLE ~~3~~ 1. Nil-ductility transition temperature data for the steel forgings.

Material	Thickness (in)	Location[*]	NDTT, (°F)[+]
A508-4A	8	Plane A	-210
	"	Plane B	-250
	12	Plane C	-230
	"	Plane D	-250
	"	Plane E	-250
A508-4B	8	Plane A	-200
	"	Plane B	-220
	12	Plane C	-170
	"	Plane D	-190
	"	Plane E	-190
A350-LF3	8	Plane A	-80
	"	Plane B	-100
	12	Plane C	-50
	"	Plane D	-60
	"	Plane E	-60

~~[*] See Fig. 1~~

[+] P2 specimens tested with nonstandard deflection height of 0.075 in.

FIG. ~~2~~1. Charpy data for the 8 in thick A508-4A forging.



ASME DESIGN
NDT = -55 -60 = -115°F
@ 50 ft.-#

A ↓ ≡ MEASURED NDT FOR PLANE A.
SEE TABLE 1.

Fig. ~~3~~2. Charpy data for the 12 in thick A508-4A forging.

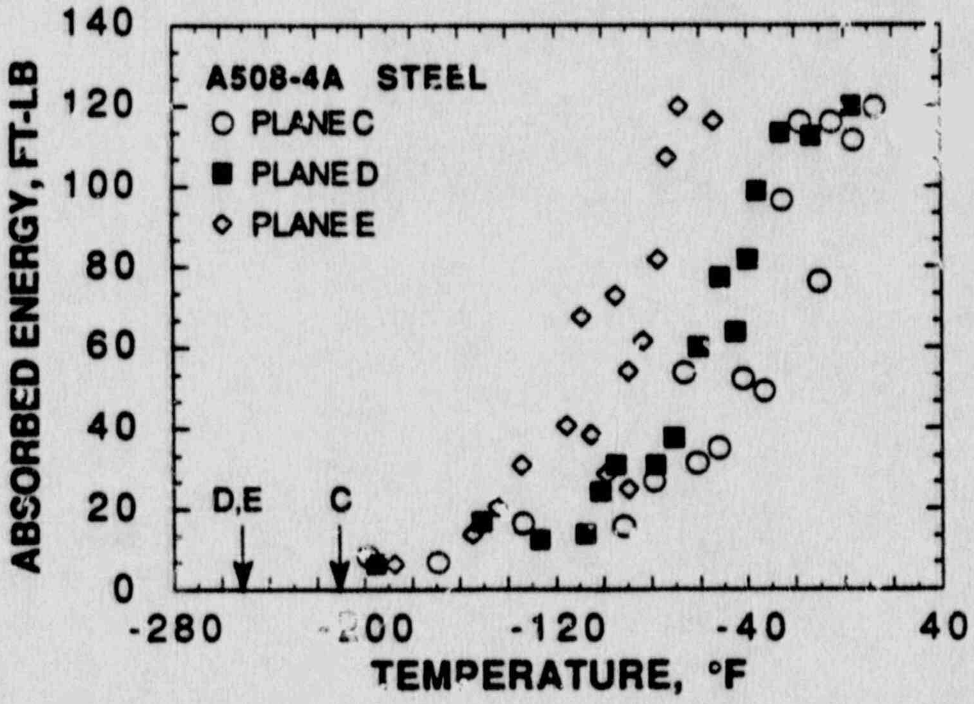


FIG. ~~4~~3. Charpy data for the 8 in thick A508-4B forging.

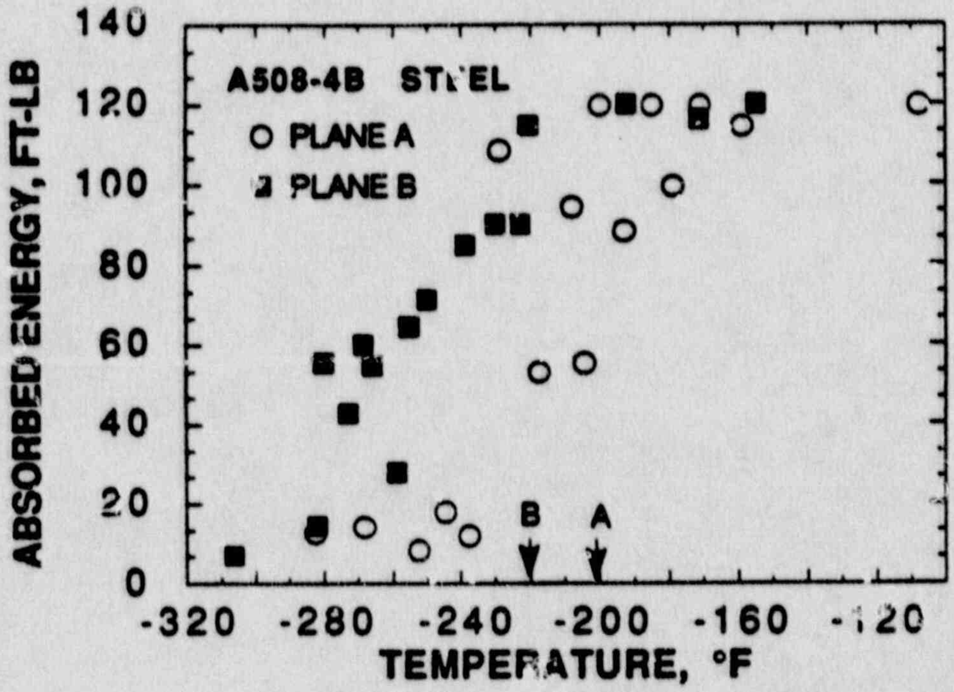


FIG. ~~5~~4. Charpy data for the 12 in thick A508-4B forging.

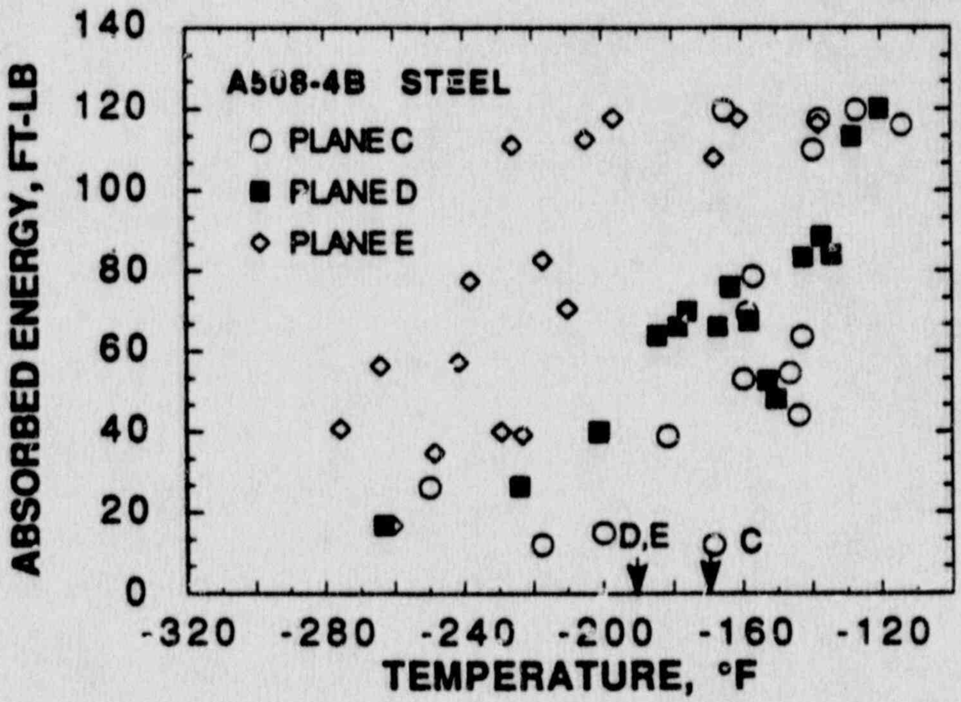


FIG. ~~6~~ 5. Charpy data for the 8 in thick A350-LF3 forging.

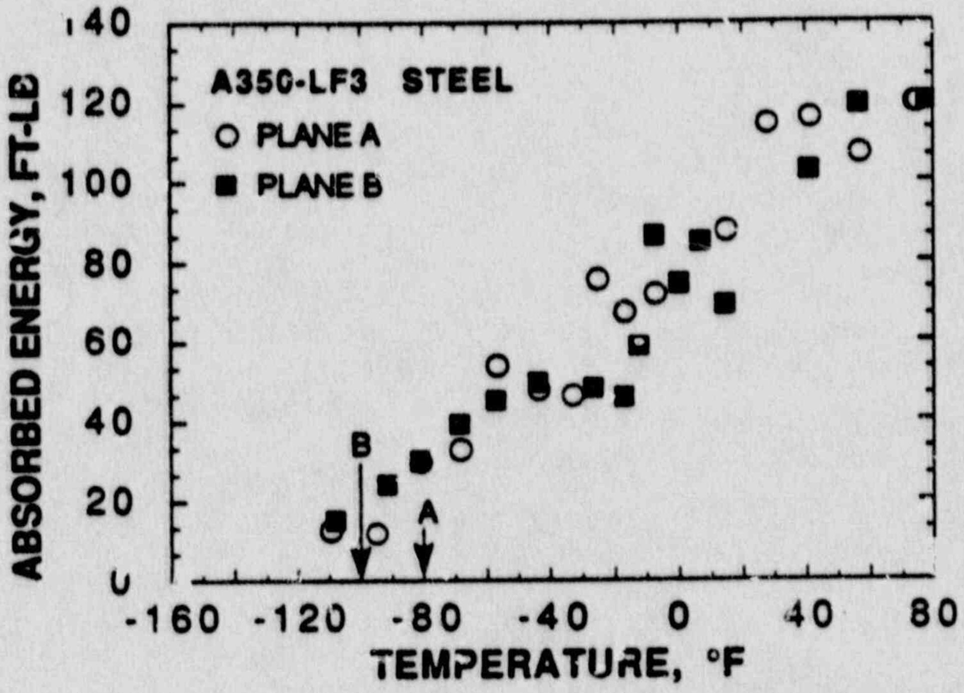


FIG. ~~7~~ 6. Charpy data for the 12 in thick A350-LF3 forging.