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G. A. Arlotta
Director, Division of Engineering
Office of Nuclear Regulatory Research
Nuclear Regulatory Commission
Washington, DC 20555

RADIOACTIVE MATERIAL SHIPPING CONTAINERS - PROPOSED NRC REGULATORY GUIDES FOR PREVENTION OF BRITTLE FRACTURE OF FERRITIC STEEL SHIPPING CONTAINERS; COMMENTS ON

Background: Title 10, Part 71 of the Code of Federal Regulations establishes the requirements for the design of radioactive material shipping containers. These requirements include surviving a hypothetical 30 foot drop at a minimum temperature of -20°F.

In 1983 and 1986, the Nuclear Regulatory Commission (NRC) forwarded for public comment two draft Regulatory Guides to protect against brittle fracture of ferritic steel shipping containers with wall thicknesses of up to four inches and greater than four inches, respectively. The regulatory guides invoke the criteria established in two contractor reports, NUREG/CR-1815 and NUREG/CR-3826, respectively. In June 1989, the NRC requested additional public comment on these Regulatory Guides.

Discussion: The approach used in the draft regulatory guides is to set requirements on the nil ductility transition (NDT) temperature depending on the shipping container wall thickness and the quantity of radioactive material contained (divided into three categories from largest to smallest curie quantity: category I, category II, and category III). If the NDT criteria are met, then brittle fracture of a shipping container at -20°F is precluded and no further brittle fracture evaluation is necessary. The NRC considers that the design and licencing processes will be expedited with issuance of these guidelines. Since 1986 the NRC has been using these draft Regulatory Guides as part of the basis for certifying radioactive material shipping containers. Consequently, for recently built shipping containers, Naval Reactors has attempted to meet the criteria.

Comments:

a. The proposed NDT temperature criteria are technically flawed. For example, the NDT requirements of -90°F to -140°F for typical shipping containers (3 to 12 inch wall thickness,

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category I or II) are far below what is needed to support a low service temperature (LST) of -20°F. The approach is based on a lower bound fracture toughness design curve for setting the NDT temperature criteria which does not allow credit to be taken for the use of higher toughness steels. The flaw size assumptions inherent in the criteria, although not clearly identified, appear to be unrealistically large (i.e., full wall thickness) and do not allow credit to be taken for good quality steels or nondestructive inspections performed during manufacture. The criteria contain apparent inconsistencies and ambiguities regarding material test methods and specimen location, the treatment of weld metal, the assumed NDT temperature allowed for ASTM A508-4 steels, and the use of categories I, II, and III. A detailed discussion of these comments is provided in enclosure (1).

b. The proposed NDT temperature criteria are not technically appropriate for this application since the net effect is to eliminate the potential use of high quality, high fracture toughness steels otherwise ideally suited to shipping container applications. HY-80 is a very high quality steel and one of the most fracture resistant ferritic steels that currently exists. Available dynamic fracture toughness data on HY-80 base and weld metal together with realistic defect assumptions would support the adequacy of this material for shipping container designs. Such applications, however, do not satisfy the proposed guidelines.

For example, in 1986, Naval Reactors placed a low service temperature restriction of 40°F on the use of a core barrel disposal container (category I) made of ASTM A352 LC2/LC2-1 (similar to HY-80) based on the Regulatory Guides. In addition, Naval Reactors is currently attempting to meet the criteria for shipment of deactivated reactor compartments (category I) made of HS, HT, and HY-80 steels and for a power unit shipping container (category II) made primarily of HY-80. In 1986, Naval Reactors changed the material during fabrication of the power unit shipping container (S-6213) from carbon steel to HY-80 to maximize its fracture toughness. However, based on material testing to date it is uncertain if these containers can be certified for a low service temperature of -20°F in accordance with the regulatory guide criteria. Therefore, the issuance of these Regulatory Guides will not aid in expediting the design or licensing process as desired by the NRC.

c. Published brittle fracture guidelines would be useful in the design and certification of radioactive material shipping containers. However, an alternate, technically appropriate set of acceptance criteria should be used for category I and II containers. Naval Reactors considers that the following provides a realistic and conservative approach for the prevention of brittle fracture.

(1) Enclosure (1) discusses an alternate approach which sets minimum dynamic fracture toughness, K_{Id}, acceptance values at the LST of -20°F for ferritic steel containment vessels based on linear elastic fracture mechanics methods.

(2) The method assumes a flaw depth of 1/10 the wall thickness, which is conservative for good quality steels.

(3) The method assumes a conservative design stress level.

The method provides conservative criteria which are considered to ensure adequate safety against brittle fracture and appear achievable for good quality ferritic steels. The above assumptions are similar to that used in brittle fracture prevention methods currently under consideration by the ASME Committee for Containment Systems for Nuclear Spent Fuel and High Level Waste Transport Packagings (NUPACK). Naval Reactors is currently planning to use this approach, where appropriate, for future Safety Analysis Reports for Packaging.

In summary, the proposed Regulatory Guides should not be issued as currently written. We are available to meet with your staff to be certain there are no unanswered questions on our proposal. We would appreciate being informed how the NRC intends to proceed on the technical issues we have raised.

C. H. Schmitt

C. H. SCHMITT
Deputy Director
for Naval Reactors

Enclosure (1) Detailed Comments on Proposed NRC Regulatory Guides for the Brittle Fracture Protection of Radioactive Material Shipping Containers

CC: See Page 4

CC:
DOE, DP-4
DOE, DP-121
Manager, PNRO (2)
Manager, PNRR (2)
Manager, SNRO (2)
Manager, SNRR (2)
C. E. MacDonald, Chief, Transportation Certification Branch, NRC
W. E. Campbell, RES/EME Branch, NRC (NLS 217B)
General Manager, Bettis
General Manager, WPAD
General Manager, KAPL
General Manager, MAO
Manager, Engineering Support Activity, WPAD
Manager, Refueling Equipment Activity, WPAD
Manager, Materials Technology, Bettis
Manager, Refueling Engineering Operations, Bettis
Manager, RSO, KAPL
Manager, MDO, KAPL
Manager, Shipping Containers, MAO
Regulatory Publications Branch, DFIPS, Office of Administration
U. S. NRC

DETAILED COMMENTS ON PROPOSED NRC REGULATORY GUIDES FOR THE BRITTLE FRACTURE PROTECTION OF RADIOACTIVE MATERIAL SHIPPING CONTAINERS

1. Overall Impact: The brittle fracture regulatory guides provide technically inappropriate acceptance criteria in that the guides preclude the use of ferritic steels in shipping containers. Even ferritic steels possessing the best fracture toughness, like HY-80 base metal and weld metal, cannot reliably meet the proposed criteria for typical shipping container designs (3 to 12 inches thick, category I or II). Naval Reactors judges that the proposed NDT temperature requirements of -90°F to -140°F for typical shipping containers are far below what is needed to support a low service temperature (LST) of -20°F. More realistic acceptance criteria should be provided.

a. Naval Reactors proposes the following alternate set of acceptance criteria for containment vessels of category I and II shipping containers. Minimum dynamic fracture toughness, K_{Id}, values are established as a function of wall thickness based on linear elastic fracture mechanics methods (fracture initiation). These values are then used as acceptance criteria to be compared with measured values of the actual material at -20°F. A brief outline of the method and an example set of criteria are provided below.

(1) Minimum K_{Id} values are established based on the linear elastic fracture mechanics equation for surface cracks. Subsurface cracks of similar size are non-limiting.

$K_I = 1.12(s)\ (\pi a/Q)^{1/2}$ applied stress intensity for surface crack (NUREG/CR-1815 Appendix A)

s applied stress
a flaw depth
Q flaw shape parameter

(2) The method assumes a flaw depth of approximately 1/10 the wall thickness from 0.25 inch (for steels less than 2.5 inch wall thickness) up to 1.2 inch (for steels of at least 12 inch wall thickness). This assumption is considered very conservative for typical steels used in the Naval Reactors program which are subjected to extensive non-destructive examinations. The surface flaw length is assumed to be six times as long as the depth, which is a standard conservative assumption made in brittle fracture analyses. Therefore, the smallest flaw

(for 2.5 inch or less thickness) is at least 1.5 inch long as seen on the surface. Steels used in the Naval Reactors program, which are typically subjected to extensive surface inspections, would reject this flaw with very high confidence.

(3) The stress is assumed to be at the design stress level.

The above flaw size and stress level assumptions are consistent with brittle fracture prevention methods currently under consideration by the ASME NUPACK Committee, "Committee on Containment Systems for Nuclear Spent Fuel and High Level Waste Transport."

The criteria appear conservative, yet achievable, and are more technically appropriate than the proposed Regulatory Guide criteria. Unlike the proposed Regulatory Guides, this method takes credit for the actual fracture toughness of the material used and allows assumption of a conservative flaw size more representative of good quality steels. For example, a lower bound K_{Id} value of 100 ksi$(in)^{1/2}$ at -20°F has recently been measured for the limiting HY-80 weld metal used in a shipping container currently being fabricated. This meets the required value of 85 ksi$(in)^{1/2}$ for a wall thickness of 4 inches as shown below.

Proposed Acceptance Criteria for HY-80
(based on $2*S_m$ stress limit)

wall thickness (inches)	K_{Id} (ksi (inch) $^{1/2}$)
≤2.5	70
4	85
6	105
8	120
10	135
≥12	145

b. The NRC accepts the use of austenitic stainless steel, since it is not susceptible to brittle fracture. However, other considerations, such as strength, weight, and cost sometimes make the use of austenitic stainless steel impractical for Naval Reactors shipping containers. Therefore, it is important that conservative, yet achievable acceptance criteria for ferritic steels be established.

2. Proposed Criteria are Inapplicable to High Strength, High Toughness Steels: The criteria in NUREG/CR-1815 are not representative of high strength high toughness steels. Design curves should be supplied which are based on K_{Id} versus temperature representative of these steels.

a. The design curves in NUREG/CR-1815 are based on a lower bound of K_{Id} testing of ASTM A-533 Grade B class 1 material (WCAP-7623 "Dynamic Fracture Toughness Properties of Heavy Section A533 Grade B Class 1 Steel Plate" by W. O. Shabbits, dated December 1970). This design curve is very similar to the K_{IR} design curve used in the ASME Boiler and Pressure Vessel Code, which lower bounds the fracture toughness of most ferritic steels. The NDT temperature of these curves corresponds to a fracture toughness level of 40 ksi(in)$^{1/2}$ and is used as the basis for deriving the NDT temperature criteria. This assumption is not technically appropriate especially for high strength, high toughness steels. For example, available literature for HY-80 shows that the dynamic fracture toughness at the NDT temperature is above 80 ksi(in)$^{1/2}$.

b. In addition, the NUREG suggests that the correlation $K_{Id}^2 = 5(CVN)E$, (CVN is the Charpy V-notch impact energy and E is Young's modulus) be used to obtain K_{Id} based on charpy data. A tabulation of correlations by the Welding Research Council (Welding Research Council Bulletin 265, "Interpretive Report on Small Scale Test Correlations with K_{Id} Data", dated February 1981) identifies this correlation as being only applicable to steels with lower yield strengths (between 36 ksi and 50 ksi).

c. As stated in Appendix B of NUREG/CR-1815 these assumptions are accurate only for steels with yield strengths less than 60 ksi and may not be accurate for higher strength steels. It is, therefore, questionable whether the NDT temperature criteria are applicable to materials with yield strengths up to 100 ksi as stated in NUREG/CR-1815.

3. Thickness Parameter and Flaw Size Assumptions: The basis for the thickness parameter and inherent flaw size assumption is unclear. NRC should clarify the basis for these assumptions.

a. It is not clear why the thickness parameter is especially significant in determining the NDT temperature requirements. The NDT temperature to support an LST of -20°F for a category II shipping container varies from -30°F to -100°F (fully dynamic loading) as the thickness varies from 0.625 to 4 inches. The change in the NDT temperature requirement appears to be too significant to be accounted for by just material constraint effects.

b. It is also not clear if the thickness parameter is related to the assumed flaw size used to develop the NDT criteria. If the thickness effect is due to an inherent through thickness flaw assumption, Naval Reactors considers this to be inappropriate. A tenth thickness flaw assumption, for example, provides adequate conservatism and is a more realistic criteria.

c. In addition, the basis for the NDT criteria for thicknesses greater than 4 inches, which is an asymptotic extrapolation of the dynamic fracture toughness curve, is unclear. The basis and applicability of the criteria for the range of steels covered by this guide should be provided.

4. Exemption of Steels Similar to ASTM A508-4. The regulatory guide for containers with wall thicknesses greater than 4 inches states that NDT temperatures -150°F and -140°F can be assumed for ASTM A508-4A and A508-4B forgings, respectively, without testing. For consistency, the NRC should extend the permitted assumed NDT temperatures for A508-4 to other Ni-Cr-Mo alloy steels, such as MIL-S-23194 composition F and HY-80 (MIL-S-16216, MIL-S-23008, or MIL-S-23009). These materials are very similar to ASTM A508-4 and are controlled to equivalent or better standards. For example, the charpy specification requirements for these materials range from 35 ft-lbs at -50°F to 50 ft-lbs at -120°F, whereas, the charpy specification requirement for ASTM A508-4 is 35 ft-lbs at -20°F.

5. Apparent Inconsistencies in the Regulatory Guides:

a. Inconsistency in Treatment of Weld Metal: The proposed regulatory guides do not provide criteria for weld fracture toughness. The proposed criteria are based on the Pellini fracture arrest approach. It appears the assumption is made that the weld metal has poor fracture toughness, but the base metal has sufficient fracture toughness to arrest cracks generated in the weld metal. This might explain why criteria for weld fracture toughness are not given. However, NUREG/CR-3019 "Welding Criteria for Use in the Fabrication of Shipping Containers for Radioactive Materials" (although not referenced directly by the proposed regulatory guides) states that fracture toughness of weld metal should meet the minimum criteria for base metals established in NUREG/CR-1815. The dynamic tear NDT temperature of carefully chosen weld metal for HY-80 used in the model 2 S-6213 power unit shipping container (now being manufactured) is approximately 60°F higher (worse) than the base material NDT. This leads to an inappropriate low service temperature (LST) restriction for shipping containers made of high strength, high toughness material.

b. <u>Inconsistency of Material Test Methods:</u> The material testing methods for determining the NDT temperature are inconsistent betweeen the two regulatory guides. For high strength steels (yield strength greater than 50 ksi), dynamic tear testing is advocated in NUREG/CR-1815 (for thicknesses up to 4 inch thick) on the basis that drop weight testing may be inaccurate, but drop weight testing is advocated in NUREG/CR-3826 (for thicknesses greater than 4 inch thick). A consistent method should be specified, since significant differences in NDT temperature may be obtained depending on the test method used. Naval Reactors notes that very little industry experience currently exists with dynamic tear testing and material vendors will not provide dynamic tear NDT certifications for acceptance.

c. <u>Inconsistency in Assumed NDT temperature of ASTM A508-4:</u>

(1) In the 1986 draft version of the regulatory guide for over 4 inch thickness, the NRC allowed an assumed NDT temperature of -158°F and -148°F for A508-4A and A508-4B, respectively, yet the current version only allows an assumed NDT temperature of -150°F and -140°F. It is unclear why these values changed. Also, the testing basis for these values should be provided to give guidance concerning the extent of testing necessary to allow an assumed NDT temperature without further NDT testing.

(2) In addition, the regulatory guide for wall thicknesses greater than 4 inches allows an assumed NDT temperature of -140°F to -150°F for ASTM A508-4, yet Figure 1 of NUREG/CR-1815 (for wall thicknesses less than 4 inches) only allows an assumed NDT temperature of -80°F for ASTM A508-4 (and for HY-80 which is similar).

d. <u>Inconsistency in Use of Categories:</u>

(1) The use of categories to set appropriate conservatism in the acceptance criteria are inconsistent between the two NUREG studies. NUREG/CR-1815 (for wall thicknesses less than 4 inches) sets different acceptance criteria depending on the curie content: category I, II, or III However, NUREG/CR-3826 (for wall thicknesses greater than 4 inches) only has a

single set of acceptance criteria regardless of the category or curie content. No explanation for this difference is given in the Regulatory Guides.

(2) The proposed acceptance criteria in NUREG/CR-1815 (for wall thicknesses less than 4 inches) are different depending on the curie content of the package based on three discrete categories: category I (largest curie content), category II (intermediate curie content), and category III (lowest curie content). The differences in the NDT requirements between the categories is very large. For example, for a two inch thick wall thickness the NDT requirement is -92°F, -75°F, and +10°F for category I, II, and III, respectively. Small changes in curie content could significantly change the acceptance criteria. A continuous scale, therefore, would be more appropriate.

6. Items Not Addressed: The following items are currently not addressed in the regulatory guides and require clarification:

a. The regulatory guides do not specify where material test specimens for determining the NDT temperature should be removed from the fabricated material. For thick material sections, specimens removed from areas close to the heat treated surface generally have lower (better) NDT temperatures than those removed further from the surface. Naval Reactors takes specimens from the center of the material, since this usually represents the worst fracture toughness.

b. The regulatory guides both state that the criteria apply only to the containment vessel of a shipping container. Naval Reactors assumes that the criteria are not applicable to other parts of the shipping container, such as impact limiters, shields, and internal structural components. Therefore, Naval Reactors recommends that these other structural components meet the material acceptance criteria for category III steels (regardless of curie content), i.e., the use of fine grain practice or charpy V-notch impact energy greater than 15 ft lbs at 10°F. This will ensure the use of good quality steel expected to be fracture resistent for structures that do not warrant the same level of control as containment vessels.