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FRACTURE TOUGHNESS CRITERIA OF BASE MATERIAL FOR FERRITIC STEEL SHIPPING CASK CONTAINMENT VESSELS WITH A MAXIMUM WALL THICKNESS OF 4 INCHES (0.1 m)

(Previously issued as Drafts MS 144-4 and DG-7001)

A. INTRODUCTION

Part 71, "Packaging and Transportation of Radioactive Material," of Title 10 of the Code of Federal Regulations requires that packages used to transport radioactive materials withstand the conditions in § 71.71, "Normal Conditions of Transport," and § 71.73, "Hypothetical Accident Conditions." In this guide, the terms packaging, shipping cask, and shipping container are used interchangeably.

The regulations require that accident conditions with an initial temperature as low as -20°F (-29°C) be considered. At this temperature, several types of ferritic steels are brittle and subject to fracture. This guide describes fracture toughness criteria and test methods acceptable to the NRC staff for use in evaluating Type B(U) and Type B(M)[1] ferritic steel shipping cask containment vessel base material having a maximum thickness of 4 inches (0.1 m) and having a maximum static yield strength of 100 ksi (690 kPa). The containment vessel is a major component of the containment system as defined in § 71.4 of 10 CFR Part 71. This guide is applicable to the containment vessel only and not to other components of the package.

Alternative fracture toughness criteria and test methods may be used provided the applicant can demonstrate that their use will ensure equivalent safety.

Any information collection activities mentioned in this regulatory guide are contained as requirements in 10 CFR Part 71, which provides the regulatory basis for this guide. The information collection requirements in 10 CFR Part 71 have been cleared under OMB Clearance No. 3150-0008.

B. DISCUSSION

This guide presents fracture toughness criteria and test methods that can be used for evaluating ferritic steel containment vessel base material having a maximum wall thickness of 4 inches (0.1 m) with a maximum static yield strength of 100 ksi (690 kPa).

Section III of the ASME Boiler and Pressure Vessel Code (Ref. 1) contains requirements for material fracture toughness; however, these requirements were developed for reactor components only and do not address hypothetical accident conditions appropriate for packaging (e.g., severe impact loads at low temperatures). Therefore, the code requirements are not directly applicable to shipping container design.

NUREG/CR-1815, "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers up to Four Inches Thick" (Ref. 2), contains background and other information

[1]Type B(U) and Type B(M) packages are defined in 10 CFR 71.4.

pertinent to the development of the criteria in this guide. These criteria are divided into three categories that are associated with the levels of safety appropriate for the radioactive contents being transported. Table 1 in this guide identifies the radioactivity limits for each of the three categories. Tables 4, 5, and 6 in NUREG/CR-1815[2] (reproduced along with Table 3 in the Appendix to this guide) list the fracture toughness criteria associated with each category. A qualitative description of the margins of safety against brittle failure for each of the three categories is given in Appendix C to NUREG/CR-1815 (Ref. 2).

Additional information regarding the basis for the criteria is contained in Appendix B of NUREG/CR-1815 (Ref. 2).

Regulatory Position 1 endorses a portion of the criteria contained in Section 5 of NUREG/CR-1815. These criteria identify material properties in accordance with the standards specified in Tables 4, 5, and 6 of NUREG/CR-1815, as appropriate.

For Category II and III containers, the highest nil ductility transition temperature (T_{NDT}) specified for the material in Table 3 of NUREG/CR-1815 (reproduced in the Appendix to this guide) may be used in lieu of conducting tests to determine the actual T_{NDT} of the material.

Table 1

	Category I	Category II	Category III
Low Specific Activity		Greater than 30,000 Ci or greater than 3,000 A_1* or greater than 3,000 A_2*	Less than 30,000 Ci and less than 3,000 A_1 and less than 3,000 A_2
Special Form	Greater than 3,000 A_1 or greater than 30,000 Ci	Between 3,000 A_1 and 30 A_1 and not greater than 30,000 Ci	Less than 30 A_1 and less than 30,000 Ci
Normal Form	Greater than 3,000 A_2 or greater than 30,000 Ci	Between 3,000 A_2 and 30 A_2 and not greater than 30,000 Ci	Less than 30 A_2 and less than 30,000 Ci

*Defined in 10 CFR 71.4

Although NUREG/CR-1815 (Ref. 2) addresses the use of ferritic steels only, it does not preclude the use of austenitic stainless steels. Since austenitic stainless steels are not susceptible to brittle failure at temperatures encountered in transport, their use in containment vessels is acceptable to the staff and no tests are needed to demonstrate resistance to brittle failure.

NUREG/CR-3019, "Recommended Welding Criteria for Use in the Fabrication of Shipping Containers for Radioactive Materials" (Ref. 3), and NUREG/CR-3854, "Fabrication Criteria for Shipping Containers" (Ref. 4), also contain information applicable to shipping containers, as does a related Regulatory Guide 7.12, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Wall Thickness Greater than 4 Inches (0.1 m) But Not Exceeding 12 Inches (0.3 m)" (Ref. 5).

C. REGULATORY POSITION

1. The criteria contained in Section 5 of NUREG/CR-1815 (Ref. 2), other than for full-scale destructive testing (5.1.4 and 5.2.4) and qualifying procedures for reduced stress levels (5.1.2), are acceptable to the NRC staff for assessing the fracture toughness of thin-wall base material (up to and including 4 inches (0.1 m)) ferritic steel containment vessels for the categories identified in Table 1 of this guide. In 5.1.2, only a value of σ/σ_{yd} equal to 1 is acceptable.

2. A Category I container qualified in accordance with this guide is acceptable for transporting either Category II or Category III radioactive materials. Similarly, a Category II container qualified in accordance with this guide is acceptable for transporting Category III materials.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this regulatory guide.

Except in those cases in which an applicant or licensee proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the methods described in this guide (which reflects public comments) will be used by the NRC staff in evaluating base material for all applications for new package designs and all requests that existing package designs be designated as Type B(U) or Type B(M) packages submitted after September 30, 1991.

[2]The following corrections should be made to the NUREG: Table 1, Category III revise to read "...Fine Grain Practice..."; Table 4, Criteria ..., third line "has $\sigma_{ys} \geq 70$ ksi, either:"; Figure 6, vertical scale should be "...0, 20, 40..."; Section 5.3.1, subsection 1, "By selecting a normalized steel ...."

REFERENCES

1. ASME Boiler and Pressure Vessel Code, Section III, "Rules for Construction of Nuclear Power Plant Components," American Society of Mechanical Engineers, New York, updated frequently.

2. W. R. Holman and R. T. Langland (under Lawrence Livermore National Laboratory contract to the NRC), "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick," U.S. Nuclear Regulatory Commission, NUREG/CR-1815,* August 1981.

3. R. E. Monroe, H. H. Woo, and R. G. Sears (under Lawrence Livermore National Laboratory contract to the NRC), "Recommended Welding Criteria for Use in the Fabrication of Shipping Containers for Radioactive Materials," NUREG/CR-3019,* U.S. Nuclear Regulatory Commission, March 1985.

4. L. E. Fischer and W. Lai (under Lawrence Livermore National Laboratory contract to the NRC), "Fabrication Criteria for Shipping Containers," NUREG/CR-3854,* U.S. Nuclear Regulatory Commission, March 1985.

5. U.S. Nuclear Regulatory Commission, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Wall Thickness Greater Than 4 Inches (0.1 m) But Not Exceeding 12 Inches (0.3 m)," Regulatory Guide 7.12,* May 1991.

*Copies may be purchased from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

APPENDIX

Tables 3 through 6 from NUREG/CR-1815, "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick," are reproduced here for the reader's convenience.

TABLE 3. NDT temperatures for steel plates.

Group	Group treatment	Thickness (in.)	NDT temperature range (°F)	ASTM specification
I. PEARLITIC: Low and intermediate strength steels (σ_{ys} = 30 to 70 ksi)				
	A As rolled	0.625 to 3	0 to 70	A36, A516, A709,
		3 to 4	20 to 90	A442, A662
	B Normalized (fine grain practice)	0.625 to 3	-50 to 10	A516, A442, A662,
		3 to 4	-30 to 30	A709
	C Normalized (high strength, low alloy)	0.625 to 3	-70 to -10	A441, A537, Cl 1,
		3 to 4	-50 to 10	A533, A588, A736
II. MARTENSITIC AND BAINITIC: High strength steels (σ_{ys} = 80 to 120 ksi)				
	D Quenched and tempered (low alloy)	0.625 to 4[a]	-90 to -30[b]	A514, A517
	E Quenched and tempered (high alloy)	0.625 to 4	-160 to -80[b]	HY-80, HY-100, A-508-CL 4 & 5, A543
III. CRYOGENIC STEELS: (σ_{ys} = 37 to 120 ksi at room temperature)				
	F See ASTM specifications	0.625 to 4	<-70°F[c]	A203
	G See ASTM	0.625 to 4	<-100°F[c]	A353, A553, A645

[a]Maximum thickness depends on hardenability.

[b]Manufacturer must certify that the NDT temperature is within this range.

[c]These steels are special cases. Each product should be tested by the DT test to determine the NDT temperature.

TABLE 4. Category I fracture toughness requirements and criteria for ferritic steels with yield strength no greater than 100 ksi.

Required degree of safety (see Appendix C)	**Very large margin of safety.**
Required amount of fracture toughness (see Sec. 5.1)	**Sufficient to arrest large cracks under dynamic loading; general yielding will precede fracture.**

Thickness (B) (in.)	**Criteria for meeting toughness requirements[a]**
0.625 to 4.0	* NDT temperature[b] must be less than a maximum value. See Fig. 3, and Secs. 5.1.1 and 5.1.2. Additionally, if the steel has $\sigma_{ys} < 70$ ksi, either: * * 5/8 in. thick DT[c] must be greater than 400 ft-lb at upper shelf temperatures. See Sec. 5.1.1. Or * C_V[d] must be greater than 45 ft-lb at upper shelf temperatures. See Sec. 5.1.1.
0.19 to 0.625	* Use DT Test E-604-80. 80% or greater shear fracture appearance required at LST. See Sec. 5.1.3. Or * Use DWTT Test E-436. 80% or greater shear fracture appearance required at LST. See Sec. 5.1.3.
0.025 to 0.19	* Use Notch Tensile Test E-338. $\frac{\text{Notch tensile strength}}{\text{yield strength}} \geq 1.0$ at LST. See Sec. 5.1.3.

[a] Full scale destructive testing on a case-by-case basis may be used as an alternate to requirements listed below. See Sec. 5.1.4.

[b] NDT is measured according to ASTM E-208, or an equivalent NDT can be established by subtracting 50°F from the midpoint of the 5/8 in. DT energy transition curve measured according to ASTM E-604.

[c] DT measured according to ASTM E-604.

[d] C_V measured according to ASTM E-23.

*Editor's Note: This line should read, "Additionally, if the steel has $\sigma_{ys} \geq 70$ ksi, either:" to correct a typographical error.

TABLE 5. Category II fracture toughness requirements and criteria for ferritic steels with yield strength no greater than 100 ksi.

Required degree of safety (see Appendix C)	Large margin of safety.
Required amount of fracture toughness (see Sec. 5.2)	Sufficient to prevent fracture initiation of cracks under dynamic loading.

Thickness (B) (in.)	Criteria for meeting toughness requirements[a]
0.625 to 4.0	* With full dynamic loading rates, NDT temperature[b] must be less than a maximum value. See Fig. 6 and Sec. 5.2.1. * With reduced loading rates, NDT temperature can be determined from Fig. 7. See Sec. 5.2.2.
0.19 to 0.625	* Use DT Test E-604-80. 50% or greater shear fracture appearance required at LST. See Sec. 5.2.3. Or * Use DWTT Test E-436. 50% or greater shear fracture appearance required at LST. See Sec. 5.2.3. Or * Use any normalized steel made to "Fine Grain Practice" or better[c]. See Sec. 5.2.3.
Less than 0.19	* No requirements when B is less than 0.19 in. See Sec. 5.2.3.

[a]Full scale destructive testing on a case-by-case basis may be used as an alternate to requirements listed below. See Sec. 5.2.4.

[b]NDT is measured according to ASTM E-208, or an equivalent NDT can be established by subtracting 50°F from the midpoint of the 5/8 in. DT energy transition curve measured according to ASTM E-604 or the NDT temperature requirement can be met by selecting the maximum NDT temperature given in Fig. 1 or Table 3.

[c]Steel with an NDT temperature lower than steels made to a fine grain practice.

TABLE 6. Category III fracture toughness requirements and criteria for ferritic steels with yield strength no greater than 100 ksi.

Required degree of safety (see Appendix C)	Adequate margin of safety.
Required amount of fracture toughness (see Sec. 5)	Sufficient to prevent fracture initiation at minor defects typical of good fabrication practices.

Thickness (B) (in.)	Criteria for meeting toughness requirements
0.4 to 4.0	• Without testing, use any normalized steel made to "Fine Grain Practice" or better[a]. See Sec. 5.3.1. Or • Show that NDT[b] ≤ 10°F (B ≥ 0.625 in.). Or • Test to show that DT[c] ≥ 50 ft-lb at 10°F, with test specimen 0.625 in. thick. Or • Test to show that C_V[d] ≥ 15 ft-lb at 10°. Or • Without testing, use as-rolled steel, provided the welds have been stress relieved and inspected by nondestructive evaluation techniques.
Less than 0.4	• No requirements when B is less than 0.4 in. See Sec. 5.3.2.

[a]Steel with an NDT temperature lower than steels made to a fine grain practice.

[b]NDT is measured according to ASTM E-208, or an equivalent NDT can be established by subtracting 50°F from the midpoint of the 5/8 in. DT energy transition curve measured according to ASTM E-604 or the NDT temperature requirement can be met by selecting the maximum NDT temperature given in Fig. 1 or Table 3.

[c]DT measured according to ASTM E-604, for specimen thickness of 0.625 in.

[d]C_V measured according to ASTM E-23.

VALUE/IMPACT STATEMENT

A draft value/impact statement was published with the draft of this guide when it was published for public comment (Task DG–7001, July 1989). No changes were necessary, so a separate value/impact statement for the final guide has not been prepared.

A copy of the draft value/impact statement is available for inspection or copying for a fee in the Commission's Public Document Room at 2120 L Street NW, Washington, DC, under DG–7001.