U.S. NUCLEAR REGULATORY COMMISSION

June 1991

REGULATORY GUIDE

OFFICE OF NUCLEAR REGULATORY RESEARCH

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)

(Previously issued as Drafts MS 501-4 and DG-7002)

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)* ferritic steel shipping cask containment vessel base material with a wall thickness greater than 4 inches (0.1 m) but not greater than 12 inches (0.3 m). 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 that can be used for evaluating ferritic steel containment vessel base material with a wall thickness greater than 4 inches (0.1 m) but not exceeding 12 inches (0.3 m).

Section III of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code (ASME B&PVC) (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 ASME B&PVC

*Type B(U) and Type (M) packages are defined in § 71.4 of 10 CFR Part 71.

requirements are not directly applicable to shipping container design.

NUREG/CR-3826, "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Greater than Four Inches Thick" (Ref. 2), contains background and other information pertinent to the development of the criteria in this guide. The criteria studied involved four approaches, which are summarized as follows.

1. A fracture arrest criterion based on an exponential extrapolation of the Pellini fracture toughness reference curve.

2. A fracture arrest criterion based on an asymptotic extrapolation of the Pellini fracture toughness reference curve.

3. A fracture initiation criterion based on the allowable flaw sizes specified in Table IWB-3510-1 of Section XI of the ASME B&PVC (Ref. 3).

4. A drop test acceptance criterion based on the introduction of flaws at critical locations in a full-scale drop test specimen.

For each approach listed above, cost and safety analyses were performed. The results of the cost analyses showed that there is no significant difference in cost impact between the two fracture arrest criteria and the other two criteria. The staff believes that fracture arrest is a more appropriate criterion for material selection for shipping containers because there is a wide variety of stresses that could occur during actual transportation accidents, and because inservice inspection for crack growth is not practical for shipping containers.

The regulatory position identifies a criterion based on the fracture arrest method for demonstrating adequate toughness of containment vessels. The regulatory position was established to ensure that materials selected have sufficient toughness to preclude brittle fracture of a through-wall crack at yield strength levels of dynamic stress.

Although the use of ferritic steels is addressed, the guide does not preclude the use of austenitic stainless steels. Since austenitic stainless steels are not susceptible to brittle fracture 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 fracture.

NUREG/CR-3019, "Recommended Welding Criteria for Use in the Fabrication of Shipping Containers for Radioactive Materials" (Ref. 4), and NUREG/CR-3854, "Fabrication Criteria for Shipping Containers" (Ref. 5), also contain information applicable to shipping containers, as does a related Regulatory Guide 7.11, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)" (Ref. 6).

C. REGULATORY POSITION

The criteria outlined below are acceptable to the NRC staff for assessing the fracture toughness of thick-wall base material (nominally over 4 inches (0.1 m), but not exceeding 12 inches (0.3 m)) of ferritic steel containment vessels.

The nil ductility transition temperature (T_{NDT}) for ferritic steels at a lowest service temperature (LST) of -20°F should be less than the value in Table 1.

Table 1
T_{NDT} Criteria for LST = -20°F

Thickness (in.)	T_{NDT} (°F)
4	-123
8	-135
12	-140

Note: Interpolation may be used to determine T_{NDT} values for different thicknesses.

Ferritic steels should be tested in accordance with ASTM E208-87a, "Standard Method for Conducting Drop-Weight Test To Determine Nil-Ductility Transition Temperature of Ferritic Steels" (Ref. 7), using specimen type P-2 or P-3. Specimen locations should be in accordance with ASTM E 208-87a, paragraph 7.

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.

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. M. W. Schwartz (under Lawrence Livermore National Laboratory contract to the NRC), "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Greater than 4 Inches Thick," U.S. Nuclear Regulatory Commission, NUREG/CR-3826,*July 1984.

3. ASME Boiler and Pressure Vessel Code, Section XI, "Rules for Inservice Inspection of Nuclear Power Plant Components," American Society of Mechanical Engineers, New York, updated frequently.

4. 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.

5. 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.

6. U.S. Nuclear Regulatory Commission, "Fracture Toughness Criteria of Base Material for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of 4 Inches (0.1 m)," Regulatory Guide 7.11, May 1991.

7. American Society for Testing and Materials, "Standard Method for Conducting Drop-Weight Tests To Determine Nil-Ductility Transition Temperature of Ferritic Steels," ASTM E208-87a, 1987.

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

REGULATORY ANALYSIS

A draft regulatory analysis was published with the draft of this guide when it was published for public comment (Task DG–7002, July 1989). No changes were necessary, so a separate regulatory analysis for the final guide has not been prepared. A copy of the draft regulatory analysis is available for inspection or copying for a fee in the Commission's Public Document Room at 2120 L Street NW, Washington, DC, under Task DG–7002.