U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH

July 1989
Division 7
Task DG-7002

DRAFT REGULATORY GUIDE

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FRACTURE TOUGHNESS CRITERIA FOR FERRITIC STEEL SHIPPING CASK CONTAINMENT VESSELS WITH A WALL THICKNESS GREATER THAN FOUR INCHES (0.1 m)

(Previously issued as Task MS 501-4)

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 vessels with a wall thickness greater than 4 inches (0.1 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.

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

Any information collection activities mentioned in this draft 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 vessels with a wall thickness greater than 4 inches (0.1 m).

Section III of the American Society of Mechanical Engineers Boiler and Pressure Vessel Code[2] (ASME B&PVC) 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). Therefore, the ASME B&PVC 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,"[3] 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.
4. A drop test acceptance criterion based on the introduction of flaws at critical locations in a full-scale drop test specimen.

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[2]Copies may be obtained from the American Society of Mechanical Engineers, United Engineering Center, 345 East 47th Street, New York, NY 10017.

[3]M. W. Schwartz (under Lawrence Livermore National Laboratory contract to NRC), U.S. Nuclear Regulatory Commission, July 1984. Copies may be purchased from the Superintendent of Documents, U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20013-7982; or from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161. A copy is also available for public inspection and/or copying at the NRC Public Document Room, 2120 L Street NW., Washington, DC.

For each approach listed above, cost and safety analyses were performed. The results of the cost analyses showed the drop test to be more costly, but there is no significant difference in cost impact between the two fracture arrest criteria and the fracture initiation criterion at yield stress levels. However, the staff believes that fracture arrest is a more appropriate method for licensing shipping containers because of the inspection requirements associated with fracture initiation and the level of safety the fracture arrest method provides in relation to the drop test and the fracture initiation criterion.

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 extensions of a through-wall crack irrespective of the crack size at yield strength levels of dynamic stress.

The nil ductility transition temperature (T_{NDT}) for a lowest service temperature (LST) of -20°F specified for the material in Table 1 of this guide may be used in lieu of conducting tests to determine the actual T_{NDT} of such material. Materials not listed need to be tested in accordance with ASTM Standard E208-84a, "Standard Method for Conducting Drop-Weight Test To Determine Nil-Ductility Transition Temperature of Ferritic Steels,"[4] to determine the T_{NDT}.

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.

Table 1 T_{NDT} Criteria

Material	T_{NDT} (°F)
SA-508-4A	-150
SA-508-4B	-140
*SA-350-LF3	-120

*Acceptable for forged section $\leq$ 4 in. thick.

[4]Copies may obtained from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

C. REGULATORY POSITION

The criteria outlined below are acceptable to the NRC staff for assessing the fracture toughness of thick-wall (over 4 inches (0.1 m)) ferritic steel containment vessels.

The T_{NDT} criteria for ferritic steels should be less than the value in Table 2.

Table 2 T_{NDT} Criteria for LST = -20°F

Thickness (in.)	T_{NDT} (°F)
4	-123
8	-135
12	-140
16	-144
20	-146

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

The T_{NDT} criteria for the materials listed in Table 1 are acceptable to the staff for containment vessels. Ferritic steels not listed should be tested in accordance with ASTM E208-84a, using specimen type P-2 or P-3.

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.

This draft guide has been released to encourage public participation in its development. 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 the active guide reflecting public comments will be used by the NRC staff in evaluating applications for new package designs and requests for existing package designs to be designated as Type B(U) or Type B(M) packages for all applications and requests submitted 90 days after publication of the final version of this regulatory guide.

BIBLIOGRAPHY

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.

Holman, W. R., and R. T. Langland (under Lawrence Livermore National Laboratory contract to the NRC), "Recom-mendations 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.

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

U.S. Nuclear Regulatory Commission, "Fracture Toughness Criteria for Ferritic Steel Shipping Cask Containment Vessels with a Maximum Wall Thickness of Four Inches (0.1 m)," Draft Regulatory Guide DG-7001, May 1989.**

*Copies may be purchased from the Superintendent of Documents, U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20013-7082; or from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

**Single copies are available at no charge on written request from the U.S. NRC, Attention Distribution Section, Document Control Branch, Washington, DC 20555.

DRAFT REGULATORY ANALYSIS

1. STATEMENT OF THE PROBLEM

Sections 71.71 and 71.73 of 10 CFR Part 71 identify normal and accident conditions that a shipping container must withstand without releasing radioactive materials that exceed specified limits. One of the accident conditions requires that containers be able to withstand a drop from a height of 30 feet (9 m) onto an unyielding surface when the ambient temperature is -20°F (-29°C). At this temperature, many steels are brittle and are subject to fracture under certain conditions of flaw size, flaw location, and stress level. Therefore, it is necessary that the containers have sufficient toughness at -20°F (-29°C) to withstand the impact loads.

There is currently no published guidance on design criteria regarding fracture toughness of thick-wall shipping containers. The possible use of ferritic steels for thick-wall container configurations makes it important that guidance on fracture toughness criteria be issued.

2. OBJECTIVES

The objectives are to establish guidance on fracture toughness design criteria that would ensure the structural integrity of shipping containers subjected to accident conditions representative of those that may occur during transport. These criteria would also aid in expediting the licensing process by providing a set of consistent levels against which fracture safety margins of specific designs can be evaluated.

3. ALTERNATIVES

The alternative is to take no action to issue guidance, but to inform applicants and licensees about the proposed guidance on an individual basis as interchanges occur between applicants and licensees and the staff during the review process.

4. CONSEQUENCES

Since the release of radioactive materials must not exceed specified limits in the event of an accident during transport, it is necessary that containers be designed to resist fracture. Fracture toughness design criteria for thick ferritic steels have been developed with NRC funds; therefore, it is important that these criteria be made available for use. Publication of these criteria and associated guidelines will aid in expediting the design process.

If no action is taken, applicants and licensees must continue to be informed on a case-by-case basis of the staff's position regarding fracture toughness design criteria, thus expending staff and industry resources that could be conserved.

5. DECISION RATIONALE

In light of the above discussion, it is concluded that the criteria should be published in a regulatory guide to inform applicants and licensees of the current staff position regarding fracture toughness criteria for thick-wall casks in order to reduce review time and expedite the design process. This proposed action would be an addition to a series of regulatory guides on the subject of shipping containers.

6. IMPLEMENTATION

This guide will be used by the staff in evaluating all new container designs. Licensees and applicants may use the guide in discussions with the staff on currently pending applications or modifications to existing container designs to be designated either Type B(U) or B(M).

* U. S. GOVERNMENT PRINTING OFFICE:1989-241-690:00141

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NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555