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Recommended Welding Criteria For Use in the Fabrication of Shipping Containers for Radioactive Materials

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Abstract

Welding and related operations are evaluated to assess the controls required to prevent weld-related failure of shipping containers used for transportation of radioactive materials. The report includes (1) recommended criteria for controlling welding as applied to shipping containers and (2) a discussion of modifications of the recommended industry Codes as applied to shipping containers.

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Preface and Acknowledgments

This report contains recommended criteria for welding and related operations used in the fabrication of shipping containers for radioactive materials. The work was done by the Lawrence Livermore National Laboratory (LLNL) and was funded by the Transportation Certification Branch within the Office of Nuclear Material Safety and Safeguards of the Nuclear Regulatory Commission (NRC).

The recommendations represent the technical judgments of the authors resulting from the review of shipping container performance requirements and fabrication practices and from consultations with the following consultants:

- Robert E. Armstrong, Lawrence Livermore National Laboratory, Livermore, CA (retired)
- Frederick J. Bush, Jr., Permutit Company, Lancaster, PA
- William R. Housholder, Nuclear Container, Inc., Elizabethton, TN
- Ernest F. Nippes, Professor of Metallurgy, Rensselaer Polytechnic Institute, Troy, NY

Criteria were selected to achieve an adequate margin of safety while allowing designers of shipping containers maximum flexibility in the choice of materials and techniques for welding.

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Recommended Welding Criteria For Use in the Fabrication of Shipping Containers for Radioactive Materials

1. Summary

This NUREG presents the recommended criteria for welding and related operations used in the fabrication of shipping containers for radioactive materials. The welding criteria given in the report are divided into three categories that are associated with the levels of safety for the type of containers and radioactive contents being transported. Category I provides the largest margin of safety; Categories II and III provide lesser margins of safety consistent with the characteristics and quantities of the radioactive material being transported. The same Category designations also have been used in the development of fracture toughness criteria applicable to the containment vessel.[1]* For each category, the welding criteria are further divided into three weld types that are associated with the functions of the welds. The three types are containment-related welds, criticality-related welds, and other safety-related welds.

The welding criteria include a number of related elements to ensure adequate control. The ten key elements are as follows:

1. Base Materials
2. Welding and Brazing Materials
3. Joint Preparation
4. Welding
5. Brazing
6. Heat Treatment
7. Qualification of Procedures and Personnel
8. Examination
9. Quality Assurance
10. Fracture Toughness.

For each Weld Type and Category, the selected welding criteria are based on an appropriate Section of the *ASME Boiler and Pressure Vessel Code*,† as summarized in Table 1. These selected Code sections provide a level of confidence consistent with the Category and Weld Type. Acceptable modifications to the ASME code to reflect shipping container application are noted in Section 4.0.

* In Ref. 1, shipping containers with ferritic steel components thicker than 4-in. or with a yield strength exceeding 100 Ksi are excluded.

† Hereafter referred to as the ASME Code or Code.

Table 1. Summary of recommended welding criteria for use in the fabrication of shipping containers.[a]

Weld type \ Category	Category I	Category II	Category III
Containment-Related Welds	ASME Code Section III, Subsection NB	ASME Code Section III, Subsection ND	ASME Code Section VIII-Div. 1
Criticality-Related Welds	ASME Code, Section III, Subsection NG		
Other Safety-Related Welds	ASME Code Section VIII-Div. 1 or Section III, Subsection NF (as appropriate)		

[a] Department of Transportation (DOT) Specifications 17C or 17H are acceptable specifications for the fabrication of drums and pails used as shipping container components.

2. Introduction

2.1 Objective and Scope of the Study

The objective of the study is to recommend acceptable welding criteria for fabricating shipping containers used to transport radioactive materials.

In scope, it covers three aspects:

1. A review of the application of welding and welding-related operations to the fabrication of shipping containers for radioactive materials
2. Development of rational guidelines for use in meeting a prescribed level of control for welding operations
3. Correlation of relevant welding criteria with other criteria, such as fracture toughness.

2.2 Categories and Types of Welds

In accordance with Ref. 1, three categories are defined in terms of the type and quantity of radioactive material being transported. Category I defines high-level quantities of radioactive materials to be transported, whereas Categories II and III define medium and low-level quantities, respectively. The welding of shipping containers can be subdivided into three functional types of welds that provide a graded approach in the selection of welding criteria within a specific category. The three types of welds are defined as follows:

- *Containment-Related Welds*: Welds included in components whose failure could cause a breach of the containment boundary
- *Criticality-Related Welds*: Welds included in components that are part of the criticality control for a shipping container
- *Other Safety-Related Welds*: Welds included in components that either protect or restrain the shipping container or welds included in components that contain safety-related elements such as shielding, coolant, or impact-absorption devices.

It is recommended that the welding requirements of ASME Code be applied to the Categories and Weld Types shown in Table 1. The recommended Code Sections provide a level of confidence consistent with the Category and Weld Type.

3. Discussion

Welding and related operations are used in the fabrication of many components that constitute a complete shipping container system. The criteria selected to control welding operations must be integrated with the design and material selection process at an early stage.

The ASME Code was selected for welding criteria because it has been proven to be a safe basis for welding various nuclear components. With only minimal modifications, selected code sections are applicable to shipping containers. Although the ASME Code does not apply directly to welding of shipping containers, it does cover all of the basic welding criteria applicable to the fabrication of shipping containers. To use the Code effectively for welding application to shipping containers, the following aspects should be considered.

3.1 Design

Some of the recommended ASME Code paragraphs provide additional information on design, however, the only effect this should have on the weld criteria in the design process is to limit material and process choices to those provided by the Code.

The safety analysis report and shipping container drawings that are submitted to secure a certificate of compliance are the controlling documents for the design, fabrication, and use of shipping containers for radioactive material. The safety analysis report may be used to document the adequacy of any special materials, methods, or tests; or to justify additions or modifications to ASME Code criteria.

3.2 Modifications

The Code refers specifically throughout its sections to pressure vessel and pressure-related welds. For purposes of this NUREG, these Code references should be understood to refer to containment-related and safety-related welds as defined in Section 2.2. References to Subsection NG

including the term core support structures should be considered as references to criticality structures. Other safety-related welds are governed by the rules of ASME Code Section VIII, Div. 1.

3.3 Examination Limitations

Shipping containers are often multiple-wall structures. Problems of access can make it difficult to examine annular closure welds. Welds within the containment boundary should be examined as stated in the Code. However, if the primary examination method or technique (e.g., radiography) is not possible on some containment- or safety-related welds because of geometry or shielding, then alternative techniques, such as ultrasonics, are acceptable.

3.4 Shielding

Shielding can create two problems. First, it can interfere with the radiography process and totally block access to joints. Second, shielding that is added as molten metal subjects the components to an unusual heating cycle. After such shielding is in place, additional heat treatment as required by the Code may not be possible. Special attention should be given to ensure that application of shielding materials does not violate the critical temperature range for any of the materials used in container fabrication.

4. Welding Criteria

Recommendations for application of the ASME Code Sections for each Category and Weld Type are summarized in Table 1. Table 2 presents this same information in more detail as related to the key welding elements. Each of these key elements is discussed below. Modifications to the Code where applicable are provided in the following paragraphs. Justification for deviations from these criteria should be included in the safety analysis report.

4.1 Base Materials

The selection of base materials is normally limited to the materials included in the Code Subsection. Welding criteria are established for each base material using the P Number designation as listed in Section IX of the ASME Code. NonCode materials may be acceptable provided that they can be readily classified into an existing P Number grouping or a comparable S Number grouping as defined in appropriate Code Cases. For example, Code Case N-71 includes an extensive tabulation of additional materials that may be acceptable for use in shipping containers.

Base materials used for ferritic steel containment vessels with wall thickness up to and including 4 in. should meet the fracture toughness criteria identified in Section 5 of NUREG/CR-1815. Fracture toughness criteria for ferritic steels in thicknesses greater than 4 in. are being developed.

Base materials to be used for components other than the containment vessel should meet fracture toughness requirements specified in the safety analysis report.

4.2 Welding and Brazing Materials

Welding and brazing materials should meet the appropriate requirements of the Code Sections and Subsections listed in Table 2. Section II, Part C, should be used in conjunction with Section III, Subsections NB, ND, NF, NG, and Section VIII.

4.3 Joint Preparation

The Code Sections and Subsections listed in Table 2 are directly applicable.

4.4 Welding

The Code Sections and Subsections listed in Table 2 are directly applicable.

4.5 Brazing

The Code Sections and Subsections listed in Table 2 are directly applicable.

Table 2. Welding criteria for shipping containers.[a]

	Containment-Related Weld			Criticality-Related Weld	Other Safety-Related Weld
Category	Category I	Category II	Category III	Categories I, II, and III	Categories I, II, and III
ASME Code / Key Welding Elements	Section III, Subsection NB	Section III Subsection ND	Section VIII-Div. 1	Section III, Subsection NG	Section VIII-Div. 1 As appropriate, Section III, Subsection NF
Base Materials	NB-2000 (except NB-2300), NB-4100, and applicable Code Cases	ND-2000 (except ND-2300), ND-4100, and applicable Code Cases	Subsection A, General Requirements appropriate parts of Subsection B, Methods of Fabrication; and Subsection C, Classes of Materials	NG-2100, NG-2200, NG-2500, NG-4100, and applicable Code Cases	Section VIII, Div. 1, Subsection A, General Requirements; appropriate parts of Subsection B, Methods of Fabrication; and Subsection C, Classes of Materials. As appropriate, Section III, Subsection NF.
Welding and Brazing Materials	NB-2400	ND-2400		NG-2400	
Joint Preparation	NB-4200	ND-4200		NG-4200	
Welding	NB-4400	ND-4400		NG-4400	
Brazing	NB-4500	ND-4500		NG-4500	
Heat Treatment	NB-4600	ND-4600		NG-4600	
Qualification of Procedures and Personnel	NB-4300	ND-4300		NG-4300	
Examination	NB-5000	ND-5000		NG-5000	
Quality Assurance	Subpart H in Title 10, Code of Federal Regulations, Part 71				
Fracture Tougnness	Paragraph 4.10				

[a] Department of Transportation (DOT) Specifications 17C or 17H are acceptable specifications for the fabrication of drums and pails used as shipping container components.

4.6 Heat Treatment

The Code Sections and Subsections are directly applicable except if it can be shown that deletion of postweld heat treatment will result in improved properties. For example, many quenched and tempered steels retain excellent properties in the heat-affected zone when properly welded. However, postweld stress relief may result in embrittlement or cracking of the heat-affected zone. Specific exclusion from Code requirements should be cited on a case-by-case basis. As noted in paragraph 3.4, postweld heat treatment of final closure welds may not be possible in containers having shielding materials added as molten metal. Any special design details or special materials should be qualified if they are used to avoid the Code postweld heat treatment requirements.

4.7 Qualification of Procedures and Personnel

The Code Section and Subsections listed in Table 2 and Section IX of the ASME Code are directly applicable to the qualification of welding procedures and personnel.

4.8 Examination

The recommended Code Section for Category I, Containment-Related Welds, is directly applicable. In those cases where the Code rules do not require nondestructive examination of weld joints, the designer should consider specifying an appropriate method of nondestructive examination.

4.9 Quality Assurance

A quality assurance program should be established and applied to the welding criteria of shipping containers. The program should meet the requirements of Subpart H, *10 CFR Part 71*.

The quality assurance program should be used to establish appropriate controls of material traceability and other documentation normally covered by Code Subsections that have not been referenced in this NUREG. For example, Subsection NCA is normally used in conjunction with Subsections NB, ND, NF, and NG.

4.10 Fracture Toughness

Fracture toughness integrity is equally important for base materials, weld heat-affected zones, and weld metal. However, the initial decisions relative to any fracture toughness criteria should be based on material properties, thickness, tensile stress magnitude, and flaw orientation. The safety analysis report should include the results of these decisions for the various component parts that constitute the complete shipping container package. Paragraph 4.1 states the criteria for ferritic steel containment vessel base material as given in NUREG/CR-1815. The fracture toughness criteria for Criticality and Other Safety-Related components should meet the requirements defined in the safety analysis report.

Fracture toughness of weld metal and the weld heat-affected zone should meet the minimum criteria for the base materials established in Paragraph 4.1. Actual test data from the welding procedure qualification test should demonstrate this compliance. The applicable ASME Code Sections, Table 1, provide guidance in requirements for number of specimens, specimen location, and orientation. Section 5 of NUREG/CR-1815 permits base material acceptance in some thicknesses and Categories on the basis of procurement specifications and as an alternate, compliance may be verified by one of the test methods indicated. Actual test data from the welding procedure qualification test should demonstrate compliance with one of the alternate tests indicated.

When the optional full-scale drop test described in NUREG/CR-1815 is used for demonstrating the toughness of a containment vessel, the welding materials and welding procedures used should be documented in accordance with the requirements of impact tested procedures as defined in ASME Code, Section IX. For the production containers, the welding materials and welding procedures should be identical to the requirements for the successful prototype container used in the full-scale drop test.

4.11 Additional Criteria

4.11.1 Fabricator's Responsibility

Fabricators of shipping containers for radioactive materials are responsible for establishing an acceptable third-party review, audit, and inspection system similar to that required for ASME

Code fabrication. A shop is approved for Section III or VIII fabrication if ASME survey teams review the shop procedures and control systems, and then regularly judge the shop for compliance. Fabricators possessing a current N- or U-type Code Symbol stamp corresponding to the applicable Code Section given in this NUREG are considered qualified for corresponding fabrication. While shipping containers will not be Code stamped, this ASME approval and review can be the basis for establishing each fabricator's competency and consistency. The fabricator's Quality Assurance Program should indicate the detailed method chosen to meet this requirement.

4.11.2 Upgrading

Welding criteria can be upgraded by Category.

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Welding and related operations are evaluated to assess the controls required to prevent weld-related failure of shipping containers used for transportation of radioactive materials. The report includes (1) recommended criteria for controlling welding as applied to shipping containers, and (2) a discussion of modifications of the recommended industry Codes as applied to shipping containers.

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