NUREG/CR-3854
UCRL-53544

Fabrication Criteria for Shipping Containers

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Prepared for
U.S. Nuclear Regulatory Commission

Lawrence Livermore National Laboratory

GPO Printed copy price: $3.00

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Manuscript Completed: April 1984
Date Published: March 1985

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Prepared for
Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555
NRC FIN No. A0374

Fabrication Criteria for Shipping Containers

Abstract

Criteria are identified for controlling the fabrication of metal* components of shipping containers used for transporting radioactive materials. The criteria have been selected from the ASME Code and are based on the level of radioactive materials being transported and the nuclear safety function of the container's components. Criteria are identified for fabrication processes which are related to materials control, forming, heat treatment, examination and acceptance testing. Implementation of the criteria will ensure the structural integrity of shipping containers at levels consistent with the radioactive materials being transported.

* Applies to all metals used in shipping containers construction except cast irons.

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Preface

This NUREG provides criteria for fabricating metal components of shipping containers used for transporting radioactive materials. The work was performed by the Lawrence Livermore National Laboratory (LLNL) and was funded by the Mechanical/Structural Engineering Branch within the Division of Engineering Technology of the Nuclear Regulatory Commission (NRC). Criteria were selected to control container fabrication while allowing designers of shipping containers maximum flexibility in the choice of materials, techniques for fabrication and acceptance testing methods.

The authors wish to thank F. J. Bush, Jr., of the Permutit Company; and C. E. Williams, G. H. Weidenhamer, and E. O. Woolridge of the NRC for their support and comments during the research and preparation of this report.

1.0 Summary

This NUREG provides fabrication criteria for the metal* components of shipping containers used for transporting radioactive materials. The criteria are divided into three categories that are associated with the levels of safety for the types and quantities of radioactive materials being transported. For each category, the fabrication criteria are subdivided into three component safety groups that are formed according to their safety function. The categories and component safety group designations are the same as those used in developing the welding criteria in Ref. 1.

The fabrication criteria are based on the American Society of Mechanical Engineers *Boiler and Pressure Vessel Code* (ASME Code),[2] as summarized in Table 1.1 for each of the categories and component safety groups. Section 4.0 of this NUREG provides the detailed fabrication criteria including any exceptions or modifications to the ASME Code. The selected ASME Code criteria provide levels of confidence in controlling fabrication processes consistent with the categories and component safety groups. The criteria should be used with the welding criteria contained in Ref. 1 when fabricating shipping containers for transporting radioactive materials.

Table 1.1. Summary of fabrication criteria based on the ASME code.[a]

Component safety group[b]	Container contents		
	Category I	Category II	Category III
Containment	Section III Subsection NB	Section III Subsection ND	Section VIII Division 1
Criticality	Section III, Subsection NG		
Other safety	Section VIII, Division 1 or Section III, Subsection NF		

[a] See Section 4.0 for detailed criteria for each category, component safety group, and fabrication process.

[b] Department of Transportation (DOT) Specifications 17C or 17H are acceptable for the fabrication of drums and pails used as shipping container components. (See paragraphs 4.2, 4.3, and 4.4.)

* Applies to all metals used in shipping containers construction except cast irons.

2.0 Introduction

2.1 Background

To protect the public health and safety, shipments of radioactive materials are required to be in accordance with the provisions of 49CFR170-189 and 10CFR71.[3,4] All activities, which are related to the design, fabrication and use of shipping containers are documented in a Safety Analysis Report (SAR) and conducted under a quality assurance program, both of which are reviewed and approved by the U.S. Nuclear Regulatory Commission (NRC). Measures are implemented to assure that the applicable regulatory requirements and the approved design provided in the SAR are correctly translated into specifications, drawings, procedures, and instructions for fabrication. The measures also assure that special fabrication processes, including forging, heat treating and acceptance testing, are controlled and accomplished by qualified personnel using qualified procedures.

All codes and standards used in the fabrication of a shipping container are identified in the SAR as part of the approved design. In the absence of any codes or standards for a special process, information which describes the process, the controls and the quality assurance measures are included in the SAR. Although the shipping container industry uses many codes and standards for fabrication, no universal code or set of criteria has been adopted by industry for fabricating shipping containers. This NUREG identifies acceptable criteria to be used in the fabrication and acceptance testing of shipping containers.

2.2 Objective and Scope

The objective of the work performed upon which this NUREG is based was to review and select acceptable fabrication criteria for shipping containers used to transport radioactive materials. The scope of the review and selection process was as follows:

(1) Fabrication processes were identified that could affect the shipping container structural integrity or safety function. Two processes, welding and brazing, were sufficiently broad in themselves that they were evaluated in a separate program and are reported in Ref. 1. Criteria are provided in Refs. 4 and 5 to ensure that quality assurance measures are established and maintained during fabrication.

(2) Criteria were identified for the fabrication of metal components of existing types of shipping containers which include monolithic structures and multi-walled structures using stainless or ferritic steel containment vessels with lead or uranium shielding. Criteria for ductile cast iron shipping containers are being developed under a separate program.

(3) Fabrication criteria were selected from existing industry codes and standards for processes that could significantly affect the container's structural integrity or safety function.

2.3 Categories and Component Safety Groups

In accordance with Ref. 6, three categories are defined in terms of the type and quantity of radioactive material being transported. Category I defines high quantities of radioactive materials to be transported; whereas, Category II and III define medium and low quantities, respectively.

The shipping container is subdivided, on a functional basis, into three component safety groups to provide a graded approach in selecting criteria for fabricating the container's components. The first group, containment components, includes all components used to retain the radioactive contents in the shipping container during transport. Containment components include the containment vessel, closure, seals, piping and bolts. The second group, criticality components, includes all components used to control nuclear criticality during the transport of fissile materials in the shipping container. The criticality components include neutron absorber materials such as boron carbide and the associated structures which retain the relative positions of the fissile and neutron absorber materials during transport. The third group, other safety components, includes all of the remaining safety related components which include: gamma and neutron shielding; secondary seals, bolts, and closures; impact limiters; lifting lugs and tie-down devices.

3.0 Discussion

A survey was performed to identify industry codes, standards and practices which could apply to the fabrication of shipping containers. Pertinent information, consultation and review on fabrication processes were obtained from the shipping container industry through personal contacts, reports and attendance of industry committee meetings. The most important code and standards identified in the survey were the ASME Code and the ASTM and ANSI Standards. The ASME Code was selected for the fabrication criteria because it has been proven to be a safe basis for controlling processes used in fabricating components for nuclear reactors. In addition, the ASME Code provides fabrication criteria to ensure various levels of safety. Although there is no specific section in the ASME Code applicable to shipping containers the shipping container industry has used the ASME Code extensively for fabricating containers over the past twenty years.

In Table 3.1, the important processes used for fabricating shipping containers and the criteria sources used for controlling them are listed. Although the ASME Code was written primarily for fabricating steel pressure vessels, criteria from the ASME Code for controlling materials, forming, heat treating, examining and hydrostatic testing can be used to control the fabrication of shipping containers. There are several fabrication processes identified in Table 3.1 that are primarily controlled not by standards but by industry practices which may be proprietary. The information provided in the following paragraphs is typical of that used for developing specific criteria for controlling those fabrication processes that are not adequately covered in existing industry standards or codes.

3.1 Shield Installation

3.1.1 Lead. Lead shielding is normally cast or poured into an annulus formed by the inner containment vessel and the outer shell of the shipping containers. The pour is made in a single continuous operation to ensure that no radiation streaming will occur at lead interfaces resulting from multiple pours.[7] To assure the adequacy and quality of the lead shielding the following should be considered:

(1) Grade and quality of the lead pig per ASTM A-29.[8]
(2) Description of the pour process which should be continuous and free of dross.
(3) Heating and melting of the lead in appropriate containers.
(4) Preheating and cooling of the shipping container walls to produce a sound shield and to minimize thermal stresses in the container walls.
(5) Cleaning of the container surfaces.
(6) Supporting of the container walls to assure concentricity and the required lead thickness.
(7) Precautions taken to minimize splashing of the lead and to prevent molten lead from impinging on the container walls.
(8) How venting and topping off of the lead are accomplished.
(9) Acceptance criteria on lead wall thickness and variation, distortion and straightness of the container walls, etc., which are consistent with the criteria specified in the SAR (see 3.2.1).

3.1.2 Uranium. Although uranium has a high melting point, moderate thermal conductivity and high strength, it has several limitations which have to be considered during fabrication. Uranium is a relatively brittle material, and is usually fabricated by making castings which are stacked together with interlocks to prevent gamma streaming. These fabrication activities for uranium shielding should be properly controlled and specified:

(1) Controls on the potential oxidation of the uranium metal.
(2) Prevention of the formation of uranium hydride.
(3) Heat treatment process to create the beta phase of the uranium and to eliminate anisotropic expansion.
(4) Specification of the uranium material.
(5) Procedures used to clad the uranium metal to prevent the interaction of the stainless steel vessel with the uranium metal at high temperatures. Also controls to prevent the sensitization of the stainless material during fabrication processes such as shrink fitting.
(6) If used, specify the detailed welding criteria and procedures.
(7) Acceptance criteria (see 3.2.1).

Table 3.1. Criteria sources for fabrication processes.[a]

Fabrication	ASME Code	Industry standard	Industry practice
Materials control	X		X
Forming, fitting and aligning	X		
Shield installation			
Steel	X		
Lead			X
Uranium			X
Heat treatment	X		
Nondestructive examination	X		
Acceptance testing			
Hydrostatic	X		
Leak		X	
Heavy lifts		X	
Gamma			X
Neutron			X
Criticality		X	X
Thermal		X	X
General processes[b]			
Machining			X
Surface finishing		X	X
Cleaning and lubricating			X

[a] Welding and brazing criteria are recommended in Ref. 1. Quality assurance criteria are provided in Refs. 4 and 5.

[b] These processes are typically not addressed in the SAR, but still must be included under the Quality Assurance Program for safety related items.

3.2 Acceptance Testing

3.2.1 Gamma Shield. Gamma scanning or probing may be used to demonstrate the soundness of the gamma shielding.[7] Alternatively, ultrasonic testing may be used. Whatever method is used, the following information should be provided in the test procedure:

(1) Description of the measuring technique including the electronics.
(2) The source type and strength used to measure the shield effectiveness.
(3) The standards and methods used to calibrate the source, sensors, and other pertinent equipment.
(4) The grid pattern used to check the shield.
(5) The type of gamma sensor used to measure the shield effectiveness.
(6) The specific test requirements and measurements.
(7) The acceptance criteria.

3.2.2 Neutron Shield. The neutron shield effectiveness should be verified by test using a neutron source of adequate strength to verify the shielding effectiveness. Information should be provided in the test procedure which is similar to that specified for the gamma shield testing in 3.2.1.

3.2.3 Criticality Control. Packages designed to transport fissile material which contain neutron absorber material should be tested to demonstrate the presence of the neutron absorber material.[9] The test description should include information similar to that requested for gamma shield testing 3.2.1. Fabrication records of the absorber material and its installation and testing should be maintained.

3.2.4 Thermal. Containers designed to transport radioactive material with decay heat should be tested to demonstrate their heat load capabilities unless otherwise justified. The test procedure should provide the following information:

(1) Test requirements and acceptance criteria.
(2) Heat load testing at various levels including rated capacity.
(3) Temperature gradients across all major materials and their interfaces.
(4) Projected peak temperatures of the simulated contents.
(5) Method used to simulate the decay heat.
(6) Ambient environment conditions during the conduct of the test.
(7) The test configuration, instrumentation and recording equipment.

3.3 General Processes

Machining operations usually determine the final dimensions and surface finish of a part. Since many factors are involved in machining, it is difficult to specify criteria which fit every case. In general, precautions should be taken to control the feed rate, cutting depth and cutting speed to ensure that the part does not overheat, deform, or receive an inadequate surface finish. Cooling fluids used in machining should not be acidic or contain significant amounts (>25 ppm) of halogens or sulfides. Processes such as welding should be accomplished prior to final machining.

Special surface finishes may be specified by the designer for gasket joints, seal surfaces, decontamination, corrosion resistance and thermal protection. Machining, glass bead impingement, and electropolishing are normally used to finish bare metals. Special surface coatings such as paints and electroplating should be applied by qualified personnel in accordance with the manufacturer's instructions.[10]

Cleaning fluids and lubricants should not be acidic or contain significant amounts (>25 ppm) of halogenated compounds, sulfides, mercury, or other deleterious materials, particularly when the container is to be submerged into reactor fuel pools. For applications requiring submergence in water the lubricants should be basically non-water soluble.

4.0 Criteria

4.1 General

The criteria for fabricating metal components of shipping containers used for transporting radioactive materials are based on the ASME Code as summarized in Table 1.1 and presented in detail in Table 4.1 and subsections 4.2 through 4.4. An acceptable method of assuring compliance with the criteria is to have the construction of a shipping container carried out by a fabricator having a valid certificate of authorization for the use of the ASME Code stamp for the appropriate section. It is not intended that the ASME Code stamp be applied to the shipping container. A fabricator having a Section III, Subsection NB, ND, or NF certificate of authorization is considered to be qualified for Section VIII fabrication and would not require a Section VIII certificate of authorization.

4.2 Category I

Acceptable criteria for the fabrication of metal components of shipping containers are contained in the ASME Code Section III, Subsection NB for containment components; Subsection NG for criticality components and Section VIII, Division I or Section III, Subsection NF for other safety components. An acceptable specification for drums and pails used in any of the component safety groups is DOT Specification 17C or better.

4.3 Category II

Acceptable criteria for the fabrication of metal components of shipping containers are contained in the ASME Code Section III, Subsection ND for containment components; Subsection NG for criticality components and Section VIII, Division I or Section III, Subsection NF for other safety components. An acceptable specification for drums and pails used in any of the component safety groups is DOT Specification 17H or better.

4.4 Category III

Acceptable criteria for the fabrication of metal components of shipping containers are contained in the ASME Code Section VIII, Division I for containment components; Subsection NG for criticality components and Section VIII, Division I or Section III, Subsection NF for other safety components. An acceptable specification for drums and pails used in any of the component safety groups is DOT Specification 17H or better.

Table 4.1. Fabrication criteria based on the ASME Code.[1]

Component safety group / Container contents	Containment			Criticality	Other Safety							
	Primary vessel, bolts, piping, fittings, valves, closure	Primary seal	Relief device	Support structures/ neutron absorber[5]	Gamma shielding[7]	Secondary bolts, shell and closure	Secondary seal	Neutron shielding, piping, fittings, valves, relief device, and tanks[8]	Lifting lugs	Impact limiters[10]	Tie down devices	Heat transfer devices
Category I	Sec. III, Subsection NB			Sec. III, Subsection NG	Sec. VIII, Div. 1[6] or Sec. III, Subsection NF							
Materials[2]	NB-2000	[4]	NB-2000	NG-2000			[4]					
Forming, fitting and aligning	NB-4200[7]		NB-4200	NG-4200								
Heat treatment	NB-4600		NB-4600	NG-4600								
Examination	NB-5000		NB-5000	NG-5000								
Acceptance testing	NB-6000[3]	[3]	NB-7000[3]						[9]			[11]
Category II	Sec. III, Subsection ND			Sec. III Subsection NG	Sec. VIII, Div. 1[6] or Sec. III, Subsection NF							
Materials[2]	ND-2000	[4]	ND-2000	NG-2000			[4]					
Forming, fitting, and aligning	ND-4200[7]		ND-4200	NG-4200								
Heat treatment	ND-4600		ND-4600	NG-4600								
Examination	ND-5000		ND-5000	NG-5000								
Acceptance testing	ND-6000[3]	[3]	ND-7000[3]						[9]			[11]
Category III	Sec. VIII, Div. 1[6]			Sec. III Subsection NG	Sec. VIII, Div. 1[6] or Sec. III, Subsection NF							
Materials[2]		[4]		NG-2000			[4]					
Forming, fitting, and aligning				NG-4200								
Heat treatment				NG-4600								
Examination				NG-5000								
Acceptance testing		[3]	[3]						[9]			[11]

Numbers shown on this page refer to following section titled "Notes."

NOTES:

1. These criteria should be referenced in the associated SAR. Criteria for special processes used, but not included in this table, should be documented in the SAR. Fabrication criteria for welding and brazing are recommended in Ref. 1. Quality assurance criteria are provided in Refs. 4 and 5. Referenced supporting portions of Section II; Section III, Subsection NCA; and Section V of the ASME Code are part of the recommended criteria.
2. The ASME Code was written for pressure vessel fabrication and does not include many of the materials used in the shipping container industry. The designer may specify the material to be used by either a commercial trade name or an applicable ASTM specification. For each material used, information or references should be included in the SAR to permit an evaluation of the materials properties and the intended use. For thicknesses up to four inches, ferritic materials should satisfy the fracture toughness criteria recommended in Ref. 11 for the relevant container category instead of the fracture toughness criteria specified in the ASME Code. Fracture toughness criteria for ferritic steel thicknesses greater than four inches are in NUREG/CR-3826. When drums or pails are used for shipping container components, the drums or pails should comply with DOT Specification 17C or 17H.
3. Leak testing of the primary containment, including seals, should be performed in accordance with Ref. 12, also see Acceptance Testing (3.2).
4. The ASME Code does not have specifications for either gasket or seal materials. The designer may specify the material and configuration by a commercial trade name. Information which demonstrates the qualification of the seal or gasket (including those used for valves and relief devices) should be included in the SAR.
5. The designer may specify a neutron absorber material by a commercial trade name or as a mixture of elements or common compounds. When appropriate, qualification data should be included in the SAR to demonstrate that the material functions as specified. When special absorber materials are used to control criticality, an acceptance test (3.2.3) should be performed for each container to ensure that the absorber material has been properly installed.
6. Specific articles in Section VIII, Division 1 have not been listed since the fabrication process is dependent on the fabrication method and materials used. Once the method of fabrication and materials of construction have been specified, the appropriate fabrication criteria can be found in Subsection A, General Requirements; Subsection B, Methods of Fabrication; and Subsection C, Classes of Materials. Criteria from equivalent ASTM materials and standards, DOT specifications or articles in ASME Code Section III, Subsection NF may also be substituted, all or in part.
7. The installation of shielding (3.1) may involve processes such as lead pouring around the primary vessel or shrink fitting of uranium castings onto the primary vessel which could affect the vessels structural integrity. In such cases, the fabrication criteria for the specific process and an engineering evaluation of any associated structural effects should be included in the SAR. Acceptance testing of the gamma shield (3.2.1) should be performed to ensure its effectiveness.
8. The designer may specify a neutron shielding material by a commercial trade name or as a mixture of elements or common compounds. When appropriate, qualification data should be included in the SAR to demonstrate that the material functions as specified. Acceptance testing (3.2.2) may be required to demonstrate the effectiveness of the neutron shielding.
9. Shipping containers involved in critical lifts in nuclear facilities should have their lifting lugs fabricated and tested to the criteria specified in Refs. 13 and 14.
10. Impact limiters may use special materials such as wood or honeycomb metals to provide the specified crushing characteristics. Any special processes, physical properties, or other information needed to install the impact limiter or qualify its proper function should be included in the SAR.
11. Heat transfer devices required to contain pressure should be hydrostatically tested to Section VIII, Subsection UG-99. Acceptance testing (3.2.4) for each shipping container may be necessary to ensure that the specified heat transfer rate is obtained.

5.0 References

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   - Section III, Rules for Construction of Nuclear Power Plant Components
     - Division 1
       - Subsection
         - NCA General Requirement for Division 1 and Division 2
         - NB Class 1 Components
         - ND Class 3 Components
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13. NUREG 0612, *Control of Heavy Loads at Nuclear Power Plants*, National Technical Information Service, Springfield, VA 22161.
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NRC FORM 335 (2-84) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

SEE INSTRUCTIONS ON THE REVERSE

1. REPORT NUMBER (Assigned by TIDC, add Vol. No., if any)

NUREG/CR-3854
UCRL-53544

2. TITLE AND SUBTITLE

Fabrication Criteria for Shipping Containers

3. LEAVE BLANK

4. DATE REPORT COMPLETED

MONTH: April YEAR: 1984

5. AUTHOR(S)

L.E. Fischer, W. Lai

6. DATE REPORT ISSUED

MONTH: March YEAR: 1985

7. PERFORMING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)

Lawrence Livermore National Laboratory
P. O. Box 808
Livermore, CA 94550

8. PROJECT/TASK/WORK UNIT NUMBER

9. FIN OR GRANT NUMBER

A0374

10. SPONSORING ORGANIZATION NAME AND MAILING ADDRESS (Include Zip Code)

Division of Engineering Technology
Office of Nuclear Regulatory Research
U.S. Nuclear Regulatory Commission
Washington, DC 20555

11a. TYPE OF REPORT

Technical

b. PERIOD COVERED (Inclusive dates)

12. SUPPLEMENTARY NOTES

13. ABSTRACT (200 words or less)

Criteria are identified for controlling the fabrication of metal* components of shipping containers used for transporting radioactive materials. The criteria have been selected from the ASME Code and are based on the level of radioactive materials being transported and the nuclear safety function of the container's components. Criteria are identified for fabrication processes which are related to materials controls, forming, heat treatment, examination and acceptance testing. Implementation of the criteria will ensure the structural integrity of shipping containers at levels consistent with the radioactive materials being transported. (*NOTE: Applies to all metals used in shipping containers construction except cast irons.)

14. DOCUMENT ANALYSIS – a. KEYWORDS/DESCRIPTORS

fabrication criteria
shipping containers
radioactive materials

b. IDENTIFIERS/OPEN-ENDED TERMS

15. AVAILABILITY STATEMENT

Unlimited

16. SECURITY CLASSIFICATION

(This page) Unclassified

(This report) Unclassified

17. NUMBER OF PAGES

18. PRICE

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555