ORNL/TM-V11656/V1
Rev. 13

SAFETY ANALYSIS REPORT FOR PACKAGING THE ORNL HFIR UNIRRADIATED FUEL ELEMENT SHIPPING CONTAINER VOLUME I

Compiled by

G.A. Aramayo
C.M. Hopper
J.R. Kirkpatrick
D.M. McGinty
J.T. Muecke
J.C. Walls

Latest Revision – Revision 13
Date of Revision – September 2020

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831-6283
managed by
UT-BATTELLE, LLC
for the
US DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

LIST OF EFFECTIVE PAGES

Volume I

Page	Revision
Cover Page	13
ii thru iv (Table of Contents)	8/7/98
v (List of Figures)	13
vi (List of Tables)	13
vii-a thru vii-j (Summary of Revision 13 changes)	13
viii (Abstract)	8
1-1	11
1-2 thru 1-5	13
1-6 thru 1-7	5
1-8 thru 1-9	10
1-10	9
1-11	5
1-12 thru 1-15	13
1-16	4
1-17 thru 1-22	13
1-23	4
1-24	13
2-1	4
2-2 thru 2-3	13
2-4	4
2-5 thru 2-6	5
2-7	7
2-8	5
2-9	4
2-10	2
2-11	4
2-12	2
2-13 thru 2-14	5
2-15	4
2-16 thru 2-21	5
2-22	7
2-23	5
2-24 thru 2-25	13
2-26	4
2-27	7
2-28	4
2-29	7
2-29a	13

LIST OF EFFECTIVE PAGES

Volume I

Note: All appendices in Chapter 4 contain reference documents. These reference documents do not reflect the revision number control system of the SAR since they were issued as separate documents.

List of Figures

Volume 1

List of Tables

Volume 1

Revision Log

Revision	Description of Changes	Approved by NRC Certificate of Compliance (CoC) Revision Number:
13	• Rev. 13 of the SARP principally involves (1) removal of RRD-FE-3, *Specification for High Flux Isotope Reactor Fuel Elements*, from Vol. I, Chapter 4, Appx. C; (2) the replacement of several controlled fuel fabrication drawings in Vol. I, Chapter 1, with two simplified fuel drawings which depict the salient fuel attributes relevant to the SARP analyses; and (3) changes to both Volumes of the SARP in support of (1) and (2). • The Cover Page and Lists of Effective Pages (LOEPs) for both Volume 1 and Volume 2 were updated to Revision 13. The LOEPs were updated to identify pages changed in this revision as Revision 13. • Updated the Revision Log for Revision 13 changes. • List of Figures, pg. v: Removed the listings for Figures 1.9 – 1.10 and 1.12 – 1.17 and replaced the detailed drawings previously included as Figures 1.7 and 1.8 with simplified drawings. • List of Tables, pg. vi: Deleted Table 1.1—SARP Controlled Fabrication Drawings. Swapped order of Tables 4.1 and 4.2 and changed title of Table 4.2 from "HFIR fuel element containment boundary" to "Characteristics of Irradiated HFIR Fuel." • Section 1.2.1.1: Moved and amended the content from the first paragraph of page 1-3 to the first paragraph of Section 1.2.1.1. Removed the sentence referencing the HFIR Fuel Specification. Added a clarifying note to the end of the second paragraph that states that burnable poison is used to control power distribution during reactor operation. • Section 1.2.3: Added a clarifying sentence regarding a polyethylene wrapping that the fuel element(s) are shipped in. Clarified the listed weights of the inner and outer fuel elements as follows to conform with weights listed in SARP Chapter 2: from 104 lb to 103.5 lb (inner); and from 202 lb to 205 lb (outer). Clarified that the fuel cladding thickness is an average of at least 0.010 in. thick, rather than a minimum of 0.010 in. thick. Clarified that the boron content listed for the inner fuel element (2.8 g) is a nominal amount.	To Be Determined* * CoC revision number will be included upon approval by the NRC.

Revision	Description of Changes	Approved by NRC Certificate of Compliance (CoC) Revision Number:
	Removed sentence referencing the elemental makeup and impurity limits detailed in the HFIR Fuel Specification and clarified that the weight percentages of uranium isotopes given provide a general description of the *radioactive* contents. • Chapter 1 Figures: Replaced Figures 1.7 and 1.8 with drawings which contain an appropriate level of detail. Removed Figures 1.9, 1.10, and 1.12 – 1.17. • Section 1.4: Deleted Reference 6 for the HFIR Fuel Specification, RRD-FE-3. • Section 2.1.2: Replaced references to Chapter 1, Figures 1.11 and 1.12 through 1.17 with "Refer to Chapter 1, Figs. 1.7, 1.8, and 1.11." • Section 2.2: Clarified that the inner and outer fuel element weights are 103.5 lbs. and 205 lbs., respectively, to be consistent with what is assumed in Chapter 2 analyses. • Section 2.7.2: Fig. 1.8 (outer fuel element drawing) is called out in Table 2.3 as depicting the plutonium nitrate container; Figure 2.6 is given as the correct figure on pg 2-24. *Both* of these are incorrect, and an editorial change has been made to cite the correct figure [Figure 2.4]. Additionally, a formatting error was corrected in Table 2.3. • Section 2.9: Deleted reference to Figures 1.9, 1.10, and 1.12 through 1.17 from the last sentence in the section. • Section 4.1: Made several editorial-type changes as follows: Amended the first sentence of Section 4.1. Deleted the second sentence which details the activity of each element (the activities are provided elsewhere in Chapter 4). Deleted the last sentence of the first paragraph referring to a table on page 4-2 and made clarifications and editorial changes regarding the tables which appear on page 4-2. Changed the final sentence of the third paragraph to read "Plate-type fuel assemblies are illustrated in Figures 1.7, 1.8, and 4.1." • Sections 4.1.3 and 4.1.4: References to Appendix C (which is the current revision of RRD-FE-3, *Specification for High Flux Isotope Reactor Fuel Elements*) in these sections have been deleted. Changed the third sentence of Section 4.1.4 from "All HFIR fuel plates are vacuum sealed at over 550°C for 3 h with a	

Revision	Description of Changes	Approved by NRC Certificate of Compliance (CoC) Revision Number:
	maximum pressure of 1 x 10-4 torr during 70% of the anneal" to "All HFIR fuel plates are program annealed at high temperature, followed by a controlled cooldown rate." This change reflects current fuel plate production processes. Made an editorial change to the final sentence on pg. 4-4 as follows: "The following sampling or verification process is…" changed to "The following verification processes are…" Changed the "Frequency per plate" for Item #5, "Destructive test to verify clad thickness and bond quality" from "1 per 171 inner plates" and "1 per 369 outer plates" to state that the sample size and frequency are based on trending data of minimum clad thickness. This change reflects current fuel plate production processes. Changed the first sentence of pg. 4-5 from "During the initial qualification of the fuel plate fabrication process, three plates per lot…" to "During the fuel plate fabrication process, a representative number of plates from different fuel plate lot numbers are destructively tested." This change reflects current fuel plate production processes. Added a clarifying statement that the fuel inside the containment boundary is a solid non-dispersible material and removed the final two sentences of Section 4.1.4. • Section 4.5 and Chapter 4, Appx. C: Deleted Appendix C. • Table 6.2, pg. 6-5: Replaced references to ORNL drawings E-42118 and E-42126, which are fabrication drawings, with Figure 1.7 (inner fuel element) and Figure 1.8 (outer fuel element). Additionally, the weight listed for the inner fuel element was changed from "about 104 lbs" to "about 103.5 lbs" for consistency with the listed weights elsewhere in the SARP. • Section 7.1: Added a clarification to Step 6 which directs the user to place the element in a polyethylene wrap or bag to protect it from dust and moisture. • Section 8: Replaced reference to Appendix C with "Section 4.1.4." Appendix C was removed from Chapter 4, and fuel verification tests are discussed in Section 4.1.4. • Tables 9-1 and 9-2: Added polyethylene foam to Q-list for the inner and outer fuel elements.	

Revision	Description of Changes	Approved by NRC Certificate of Compliance (CoC) Revision Number:
	• Section 9.3.3: Moved and amended information regarding the fuel fabrication process in the design control section from pg. 9-12 to 9-11. Changed “refer to Chapter 1, Figures 1.3 through 1.10, 1.12 through 1.17” to “refer to Chapter 1, Figures 1.3 through 1.8” in the fourth line of the third paragraph. Removed parenthetical note regarding the HFIR Fuel Specification in Chapter 4, Appendix C, at the end of the fourth paragraph. • Section 9.3.5: Under "Instructions, Procedures, and Drawings," removed "(NOTE: This document is found as Appendix C in Chapter 4, 'Containment.')" • Section 9.3.9: Under "Control of Processes Affecting the Fuel Elements," removed "(NOTE: This document is found as Appendix C in Chapter 4, 'Containment.')" Under "Control of Processes Affecting the Fuel Elements," removed "…Section X of…" from the third line of the second paragraph.	
12	• Rev. 12 of the SARP addresses a latent error found in Appendix B of the Chapter 3 thermal analysis. The amount of melting predicted to occur in this postulated scenario was skewed by the use of pre-machined HFIR fuel element side plate thicknesses in the calculations rather than the final assembly dimensions. Additionally, the A_2 value previously calculated has been updated to the latest regulations. Vol. II of the SARP is not affected by these changes; thus, the only change in Vol. II is to the revision level. • The Cover Page and LOEPs for both Volume 1 and Volume 2 were updated to Revision 12. The LOEPs were updated to identify pages changed in this revision as Revision 12. • Updated the Revision Log for Revision 12 changes. • Section 2.1.2: Revised language in first full paragraph of pg. 2-2 from “0.1 Ci (A_2 quantity)” to “an A_2 quantity” since the previous A_2 quantity is no longer applicable under current regulations. • Section 2.7.3: Revised the second sentence of the section to state “…less than an A_2 amount of radioactive material will be released.” This section has been updated for the revised	21

Revision	Description of Changes	Approved by NRC Certificate of Compliance (CoC) Revision Number:
	analysis which corrects a latent error in Chapter 3, Appendix B, and updates the A_2 value to be consistent with current regulations. • Section 3.5: Revised the third sentence of the fourth paragraph in Section 3.5 (pg. 3-7) to state "…an A_2 amount of radioactive material will be released...". • Ch. 3, Appendix B, LOEP, pg. 3-B-1: Editorial change to update revision level for pages 3-B-1, B-1 through B-4, B-8, and B-9. • Ch. 3, Appendix B, Summary, pg. B-1: Changed the predicted amount of melted fuel in the fourth sentence to reflect the revised analysis in Chapter 3, Appendix B. • Ch. 3, Appendix B, pgs. B-2 through B-4 and B-8: Revised the applicable portions of the calculation section of Ch. 3, Appendix B, and provided references to the correct drawings for side plate dimensions for the inner and outer fuel elements. Updated the conclusion of calculation analysis to reference to reflect that the Appendix B test now begins at the NCT maximum temperature of 169ºF. • Ch. 3, Appendix B, References, pg. B-9: The references to the manufacturing side plate drawings were deleted. References for the side plate dimensions now call out the fuel assembly drawings in Chapter 1. • Section 4.1, pg. 4-3 and (new) pg. 4-3a: Discussions of the fuel material and associated A_2 values for the inner and outer fuel elements were updated to reflect the current regulations. • Section 4.3.3, pgs. 4-8 and 4-9: This section was updated to reflect that, at a minimum, releases of greater than 90 % of the fuel from an inner element and greater than 34% of the fuel from an outer element are necessary to release an A_2 amount of material. Additionally, the second paragraph was updated to reflect that the analysis in Ch. 3, Appendix. B, concludes that less than 25% of the fuel-bearing material from a fuel element will melt in the HAC thermal test when the container is not present.	
11	• The Cover Page and LOEPs for both Volume 1 and Volume 2 were updated to Revision 11. The LOEPs were updated to identify pages changed in this revision as Revision 11.	20

Revision	Description of Changes	Approved by NRC Certificate of Compliance (CoC) Revision Number:
	• The Summary of Revision page in Volume 1 was replaced with a detailed revision log in Volume 1. The Summary of Revision page in Volume 2 was revised to refer the reader to the detailed revision log in Volume 1. • Section 1.1 and the introductory paragraph in Chapter 6 were revised to clarify that since current regulations no longer use Fissile Classes. A Criticality Safety Index of 0.4 is specified in the CoC. • An editorial change was made to Section 1.1 to clarify that the containers comply with regulations in effect as of the date of the original application. • Section 1.2.1, a typographical error was corrected related to the wood post glued to the inside wood base 4 ¼ inches from the center of the cask, as this dimension is shown on drawing M-20978-EL-002, Rev. E (included as Figure 1.3) • Table 1.1 was revised to correct the drawing number listed for the HFIR Outer Fuel Element – Outer Side Plate. • Figure E-20 in Appendix E of Chapter 2 was replaced with a copy that was redrawn to improve legibility. Revision level indicated for this figure was not changed because no technical changes were made in the figure. • The LOEPs for Appendix C of Chapter 2 (page 2-C-1) was revised to change the indicated revision level of page 42 from Rev 4 to Rev 7. Page 42 was previously revised as part of the revision 7 update, but the indicated revision level was inadvertently left at Rev 4 on the LOEPs. • The microfiche previously included as Appendix 3.6.A was replaced with a printout of the microfiche contents to facilitate conversion of the document to an electronic format. The associated title page for the appendix was revised to delete reference to the microfiche. • Photos 1-6 in Chapter 4, Appendix A were replaced with more legible copies. Revision level indicated for this appendix was not changed because no content changes were made in the appendix. • Appendices B and D in Chapter 4 were replaced with more legible copies. Revision level indicated for these appendices was not changed because no content changes were made in the appendices.	

Revision	Description of Changes	Approved by NRC Certificate of Compliance (CoC) Revision Number:
	• Chapter 9, Section 9.1, Introduction, first paragraph, added wording to clarify that users of the containers must be registered Users and must maintain an acceptable Quality program. • Editorial changes were incorporated in Chapter 9 to reflect current organizational structure, current document identifiers, and make minor clarifications.	
CoC Rev 19 made editorial changes in the CoC, and no changes to the SARP.		19
10	• Volume 1 and Volume 2 cover pages were revised to update the revision level and date. • The lists of effective pages for Volumes 1 and 2 were revised to reflect the changes in Revision 10. • The "summary of changes" page for each volume was revised to list changes in revision 10 of the document. • Sections 1.2.1.1, 1.4, 4.5, 9.3.3, 9.3.5, 9.3.6, and 9.3.9 were revised to cite the most recent revision of the fuel element specification, RRD-FE-3. • Table 1.1 was revised to cite the most recent revision of the drawings listed in the table. • Drawings M-20978-EL-002E and M-20978-EL-003E, included as Figures 1.3 and 1.4 were revised to include the trefoil label required by 49 CFR 172 Appendix B. • Drawings E-42118, E-42126, D-42114, and D-42122, included as Figures 1.7, 1.8, 1.14, and 1.17 respectively, were updated to incorporate editorial changes and to reflect the results of improved inspection techniques implemented at the fuel fabricator. • Chapter 4, Appendix C was revised to include the most recent revision of RRD-FE-3, the fuel element specification.	18
9	• Volume 1 and Volume 2 cover pages were revised to update the revision level and date. • The lists of effective pages for Volumes 1 and 2 were revised to reflect the changes in Revision 9. • The "summary of changes" page for each volume was revised to list changes in revision 9 of the document. • Drawings M-20978-EL-002E and M-20978-EL-003E, included as Figures 1.3 and 1.4 respectively, were revised to include new plywood specifications that facilitate maintenance on the containers. *(CoC Rev 14 included*	17, 16, 14, 13, 12

Revision	Description of Changes	Approved by NRC Certificate of Compliance (CoC) Revision Number:
	approval of changes in the plywood specification shown on drawings M-20978-EL-002E and -003E.) • Drawing M-20978-EL-008E, included as Figure 1.5, was revised to update nameplate information. (*CoC Rev. 13 included approval of nameplate changes on drawing M-20978-EL-008E. CoC Rev. 12 included reference to the September 1996 submittal, however it did not include approval of the change.*) • Drawings D-42114 and D-42122, included as Figures 1.14 and 1.17 respectively, were revised to change the maximum allowable distance between the fuel area and the edge of the fuel element plate. These changes were based on use of more sensitive radiographic inspection techniques by the fuel fabricator. (*CoC Rev 17 included approval of changes in the allowable distance between the fuel area and edge of the fuel element plate as shown on drawings D-42114 and D-42122. These drawing changes were originally submitted in August 2007. Revision 16 of the CoC cites the August 2007 submittal but the revised drawings were not listed until Revision 17 of the CoC.)*	
	CoC Rev 15 made no changes to the SARP.	15
8	• Volume 1 cover page was revised to update the revision level and date. • The list of effective pages for Volume 1 was revised to reflect the changes in Revision 8. • The "summary of changes" page for Volume 1 was revised to list changes in revision 8 of the document. (No changes were made to Volume 2.) • Minor editorial changes were made in the Table of Contents, List of Figures, List of Tables, and Abstract to address discrepancies identified by an internal self-assessment. • Drawings E-42118 and E-42126, included as Figures 1.7 and 1.8 respectively, were revised to change reference to drawings: M-11524-04-101-D and M-11524-04-102-D to M-11524-OH-101-D and M-11524-OH-101-D. (*CoC Rev 13 included approval of these drawing changes – CoC Rev 12 included reference to the request for this change but did not include approval of the change)*	13, 12
	CoC Rev. 11, no changes were made to the SARP	11

Revision	Description of Changes	Approved by NRC Certificate of Compliance (CoC) Revision Number:

7	• Volume 1 and Volume 2 cover pages were revised to update the revision level and date.
	• The lists of effective pages for Volumes 1 and 2 were revised to reflect the changes in Revision 7.
	• The following changes were made to incorporate clarifications included in the DOE letter from Michael Wangler to Charles MacDonald of NRC, dated February 26, 1992:
	  o Table 2.1 was revised to include bolting material properties
	  o Section 2.7.1.2 and Section 6.4 of Appendix C were revised to clarify acceptable strength of the closure bolts.
	  o Section 2.7.6 was revised to include a summary of cumulative damage.
	  o Table 6.2 was revised to add a value for density for the Al cermet.
		9

6	• Sections 1.2.3, 4.1, 5.2, and Table 6.2 were revised to change the maximum U^{235} content from 2.6 kg to 2.63 kg and from 6.8 kg to 6.88 kg for the inner and outer fuel element containers, respectively. • An existing supplement was added to the fuel element specification, included as Chapter 4 Appendix C, to ensure that all fabrication documentation is included in the SARP. The supplement provided specifications for U_3O_8 provided by ORNL to the fuel fabricator.	10
5	Revision 5 was the first revision of the SARP submitted for NRC review. A detailed description of the changes incorporated in this revision is not available. The changes included in revision 5 addressed the final set of comments from the DOE review in preparation for submitting the document to the NRC for upgrading the CoC from B( )F to B(U)F. The following pages were changed in revision 5: Chapter 1 • 1-1 through 1-4; 1-6; 1-7; 1-11; 1-18; 1-19; 1-21; & 1-22. Chapter 2 • 2-2; 2-3; 2-5 through 2-8; 2-13; 2-14; 2-16 through 2-24; 2-27; selected pages in Appendix C, selected pages in Appendix E; and selected pages in Appendix F.	9, 8

Revision	Description of Changes	Approved by NRC Certificate of Compliance (CoC) Revision Number:
	(CoC Rev 8 invoked the maintenance program and operating procedures from ORNL/TM-11656 (submitted with May 30, 1991 DOE letter), but did not invoke new bolt specification, etc. for upgrade to meet B(U)F. CoC Rev 8, and prior revisions cited ORNL/ENG/TM-9 as the applicable safety analysis. *CoC Rev 9 upgraded the designation from B( )F to B(U)F. Drawings included in SARP, Rev. 5, Chapter 1 cited correct bolt specifications and blocking device. Procedures described in SARP, Rev. 5, Chapter 7 included blocking device. With the upgrade to B(U)F designation, references to ORNL/ENG/TM-9 were removed from the CoC and replaced with ORNL/TM-11656.)*	
4 – 0	This document was prepared to demonstrate compliance with then-current regulations and allow upgrading the CoC from B( ) to B(U)F. Revisions 0 through 4 were reviewed by DOE, but not by the NRC. Revisions 1 through 4 addressed comments that resulted from DOE review of the SARP in preparation for submittal to NRC. A detailed description of the changes incorporated in revisions 1 through 4 is not available. See the ORNL letter from H. A. Glovier to H. Randall Fair of DOE, dated April 26, 1991, Subject: “Responses to DOE-HQ Evaluation of Q0/Q1/Q2 Questions on the DOE Certificate of Compliance (No. 5797) License Renewal Request for the High Flux Isotope Reactor Unirradiated Fuel Shipping Containers” for submittal of SARP revision 4 changes.	Not applicable

is 31.5 OD by 45.75 inches high and has a cavity 17.38 inches ID by 31.12 inches long. The gross weights are 660 and 1050 pounds, respectively.

The bottom plate is welded to the shell. Sixteen 3/8-inch x 1-inch ASTM A449-Gr C carbon steel bolts and ASTM A563-GR C carbon steel nuts with stainless steel flat and lock washers attach the lid to a 2 x 2 x 1/8-inch ASTM A36 structural steel angle flange welded around the top of the outside of the shell.

A 1/8-inch thick neoprene gasket lies between the lid and the angle flange. The gasket does not provide a pressure seal; its purpose is to exclude rainwater. The gasket does not provide a pressure seal because the sealing surfaces were not machined nor maintained parallel during fabrication; four weep holes are provided in the angle flange to ensure venting.

Three 1 x 1 x 1/8-inch ASTM A36 steel reinforcing angles are welded around the outside of the shell, one at the midpoint and one 15 inches above and below the midpoint. An additional 2 x 2 x 1/8-inch reinforcing angle is welded to the shell at the lid flange angle. Six inches of laminated Douglas fir plywood lines the inside of the shell and acts as thermal insulation. The plywood is lined with 1-inch of polyethylene foam, which serves as a shock absorber to protect the contents from physical damage. In the outer fuel element model, a 2-inch diameter wood post is glued to the inside wood base 4 1/4-inches from the center of the cask to make it impossible to load both inner and outer fuel elements into the container.

1.2.1.1 Fuel. The radioactive contents of the research reactor fuel elements that are typically classified as MTR-type fuel (such as HFIR) are contained in a fuel matrix and clad in aluminum which together provide a containment that withstands the combined effects of the structural and thermal tests for normal and accident conditions when transported in the HFIR unirradiated fuel element containers. The salient design features of the assembled fuel element are provided in Figures 1.7, and 1.8. The detail containment boundary information is included in Chapter Four, “Containment,” Section 4.1, “Containment Boundary.”

Each fuel core, which constitutes a rectangular parallelepiped, consists of two mating sections: (1) a fuel section, varying in thickness across the width, and (2) an aluminum filler section which in the inner fuel element contains a burnable poison in the form of B4C. The fuel and burnable poison surface densities are varied across the width of each plate to help control the power distribution during reactor operation.

The fuel element fabrication is a highly controlled operation with specific criteria defined for the fuel plate and end adaptor attachment welds.

The information for the remainder of this page has been deleted.

1.2.2 Operational Features

The containers are designed to be lifted by forklift truck and to be shored and blocked into place during shipment like conventional shipping drums. The lid of the container can be removed after removing the tamper proof seal wire, the 16 nuts, washers, and bolts, and the lid-lifting blocking device. The lid is designed to be lifted by hooks inserted in the open ends of one of the angles welded to the top of the lid. The lid-lifting blocking device (Figure 1.6) is designed to prevent the inadvertent lifting of the container during transportation.

1.2.3 Contents

As mentioned in Section 1.1, the packages are designed to carry the inner and outer fuel elements that form an unirradiated HFIR fuel assembly. Prior to shipment each fuel element is wrapped in polyethylene to maintain cleanliness. A photograph of the HFIR fuel assembly is shown in Figure 1.11. The outer fuel element contains 369 50-mil-thick involute geometry fuel plates with 50-mil-thick channels between plates. The amount of ^{235}U per plate is 18.44g +/-1%, making a maximum total of 6.88 (rounded up from 6.8724) kg in the outer element. The inner fuel element contains 171 50-mil-thick involute geometry fuel plates with 50-mil-thick channels between plates. The amount of ^{235}U per plate is 15.18g +/-1%, making a maximum total of 2.63 (rounded up from 2.6217) kg in the inner element. The uranium in both elements is in the form of U_3O_8 -Al cermet clad by an average of at least 10-mil-thick aluminum. A nominal total of 2.8g of ^{10}B is incorporated in the aluminum filler material of the inner element only. Heat generation of the shipping container contents shall not exceed 0.1 watt. (Note: The heat generated by enriched uranium containing 12,000 grams of ^{235}U is less than 1.0 watt.)[7] Therefore, heat output of either unirradiated HFIR fuel element alone is negligible.

The inner element of the HFIR fuel assembly weighs 103.5 pounds; the outer element weighs 205 pounds. The following percentages are representative of the general description of the radioactive contents:

^{234}U	1.010%
^{235}U	93.164%
^{236}U	0.389%
^{238}U	5.437%

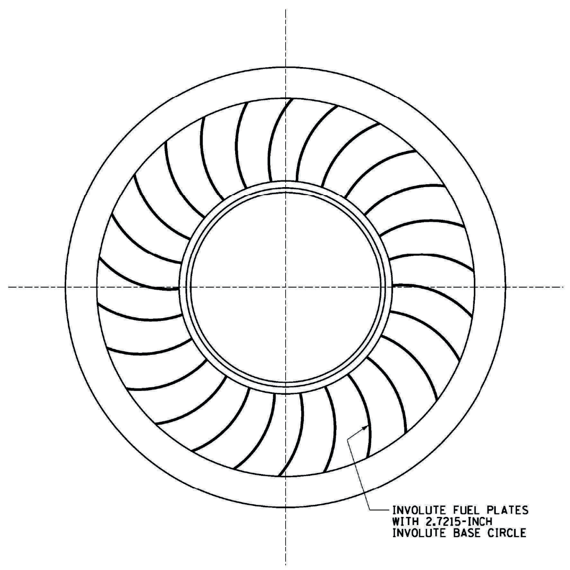
Deleted

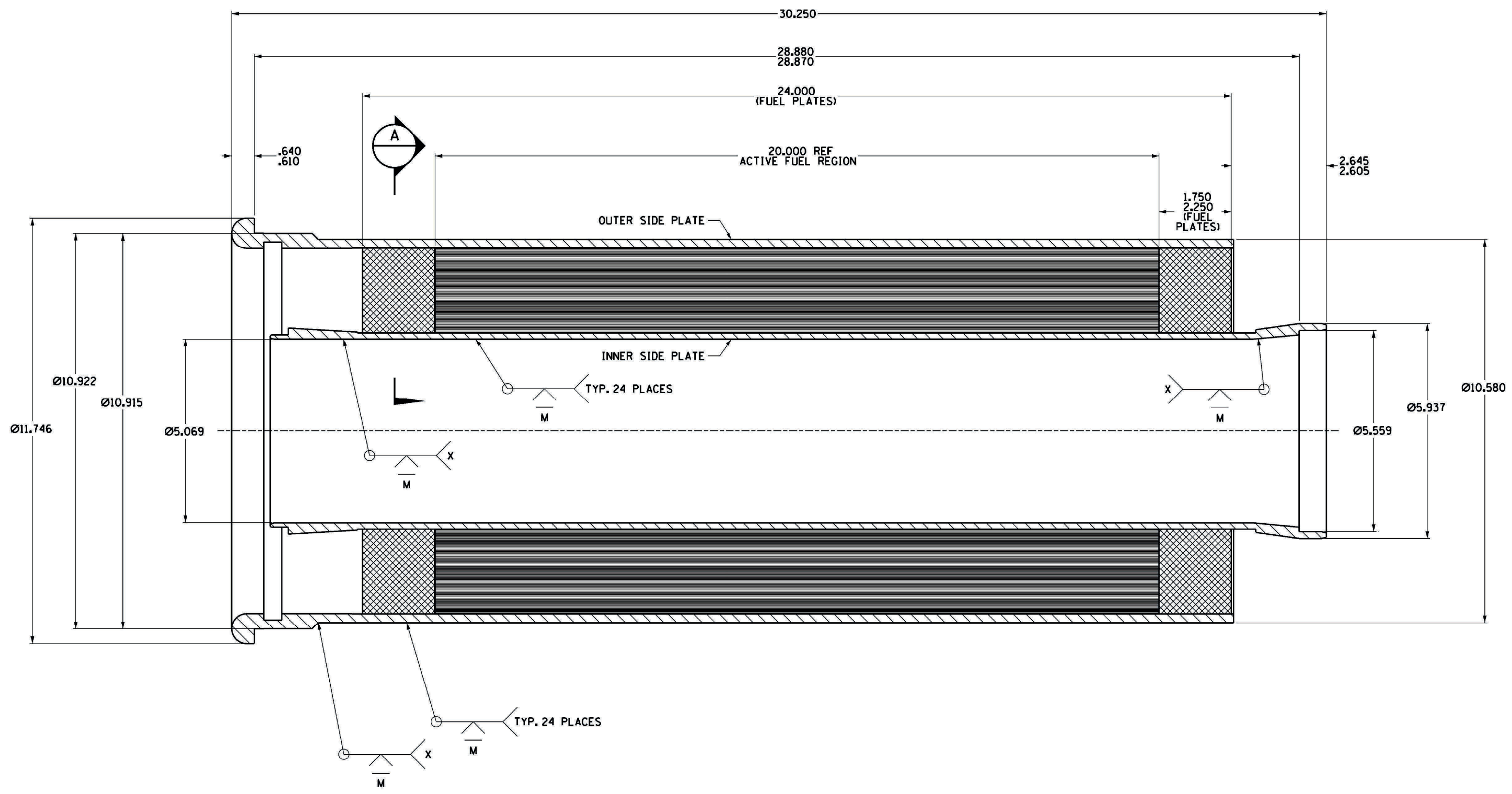
Drawing Attached

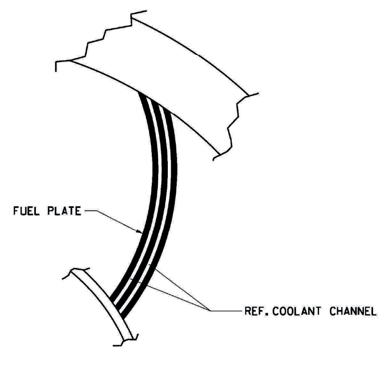
Fig. 1.7. HFIR Fuel Unirradiated Inner Element Certification Drawing—M-11524-OH-106 (Rev. 4).

GENERAL NOTES:

1. FUEL ELEMENT NOMINAL WEIGHT IS 103.5 LB.
2. FUEL ELEMENT U-235 CONTENT IS 2570G. MIN./2621G. MAX.
3. FUEL ELEMENT B-10 CONTENT IS 2.5308G. MIN./3.078G. MAX.
4. ALL DIMENSIONS ARE ±.005 UNLESS OTHERWISE NOTED.
5. MATERIAL OF CONSTRUCTION:
   INNER AND OUTER SIDE PLATES - AL 6061
   FUEL PLATE -
   CORE: U_3O_8 (ENRICHMENT 92-94%) + AL POWDER + B_4C POWDER (CERMET)
   CLADDING: AL 6061
6. MINIMUM FINISHED MACHINED SIDE PLATE THICKNESS IS:
   INNER SIDE PLATE - 0.048 INCHES
   OUTER SIDE PLATE - 0.105 INCHES
7. COOLANT CHANNEL THICKNESS (DISTANCE BETWEEN FUEL PLATES) IS 0.050 ± 0.010 INCHES.
8. BOTH THE FUEL PLATES ATTACHMENT WELDS AND ADAPTOR WELDS ARE FULL PENETRATION JOINTS COMPLETED BY AUTOMATED GAS METAL ARC WELDING PROCESS. WELDS ARE SUBSEQUENTLY MACHINED ALONG WITH ELEMENT TO OBTAIN FEATURES NOTED ON THIS DRAWING.
9. ADAPTOR WELDS ARE INSPECTED BEFORE FINAL MACHINING BY RADIOGRAPHY. BOTH FUEL PLATE ATTACHMENT WELDS AND ADAPTOR WELDS ARE VISUALLY INSPECTED AFTER FINAL MACHINING.
10. THE MINIMUM AVERAGE CLADDING THICKNESS IS 0.010-INCHES.







SECTION A-A

NOT FOR FABRICATION

LICENSING RESTRICTIONS APPLY

REVISION CERTIFIED FOR CONSTRUCTION AUG 26 2020

REFERENCE DRAWINGS	NUMBER
HFIR INNER FUEL ELEMENT ASSEMBLY	E-42118
HFIR FUEL UNIRRADIATED OUTER ELEMENT CERTIFICATION DRAWING	M-11524-OH-107
SHIPPING CONTAINER FOR UNIRRADIATED INNER HFIR ELEMENT ASSEMBLY	M-20978-EL-003

NO.	REVISIONS	DESIGNER / TASK LDR	REVIEWER / SAFETY	Q.A.S. / C.C. MGR	APPROVED / MAINT MGR	OPS. MGR / DATE
4	SEE DCN 13590	CED/TJ / DLP	CPK / WBK	N/A / KBN	N/A / N/A	N/A / 8-26-20
0	SEE DCN 13433					

DESIGNER	DATE	SAFETY ANALYST	DATE	APPROVED	DATE
T.W. Evans/TAJ	2-28-20	N/A	-	N/A	-
TASK LEADER	DATE	Q.A. SPECIALIST	DATE	MAINT MGR	DATE
D. L. Pinkston	2-28-20	N/A	-	N/A	-
DESIGN REVIEWER	DATE	CFG. CONTROL MGR	DATE	OPERATIONS MGR	DATE
C. P. Kilgore	2-28-20	K. B. Napier	3-2-2020	N/A	-

GENERAL SPECIFICATIONS
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
REMOVE BURRS/BREAK EDGES
FRACTIONS ± N/A
xx DECIMALS ± N/A
xxx DECIMALS ± N/A
ANGLES ± N/A
FILLETS N/A MAX.
MACHINE FINISH N/A √ MAX.
SCALE: NONE

CAUTION NUCLEAR EQUIPMENT:
ANY PROCESS OR MATERIAL (INCLUDING PACKAGING AND SHIPPING MATERIALS) THAT HAS THE POSSIBILITY OF LEAVING A RESIDUE CONTAINING ANY OF THE HALIDE ELEMENTS (PRIMARILY CHLORINE AND FLUORINE), METALLIC ELEMENTS (PRIMARILY COPPER, LEAD, NICKEL, SILVER, THORIUM, AND TIN) OR CARBON/GRAPHITE ON THE SURFACE OF ANY HFIR COMPONENT AFTER FINAL CLEANING SHALL NOT BE USED. MERCURY IN ANY FORM SHALL BE SPECIFICALLY PRECLUDED IN THE PROCUREMENT OF ALUMINUM RAW MATERIALS AND IN ALL PROCESSING AND MANUFACTURING OPERATIONS.

OAK RIDGE National Laboratory — HIGH FLUX ISOTOPE REACTOR
Managed by UT-Battelle for the US Department of Energy
RESEARCH REACTORS DIVISION

FACILITY H.F.I.R. BLDG. NO. 7900

HFIR FUEL
UNIRRADIATED INNER ELEMENT
CERTIFICATION DRAWING

M-11524-OH-106 E REV. 4

AS DESIGNED

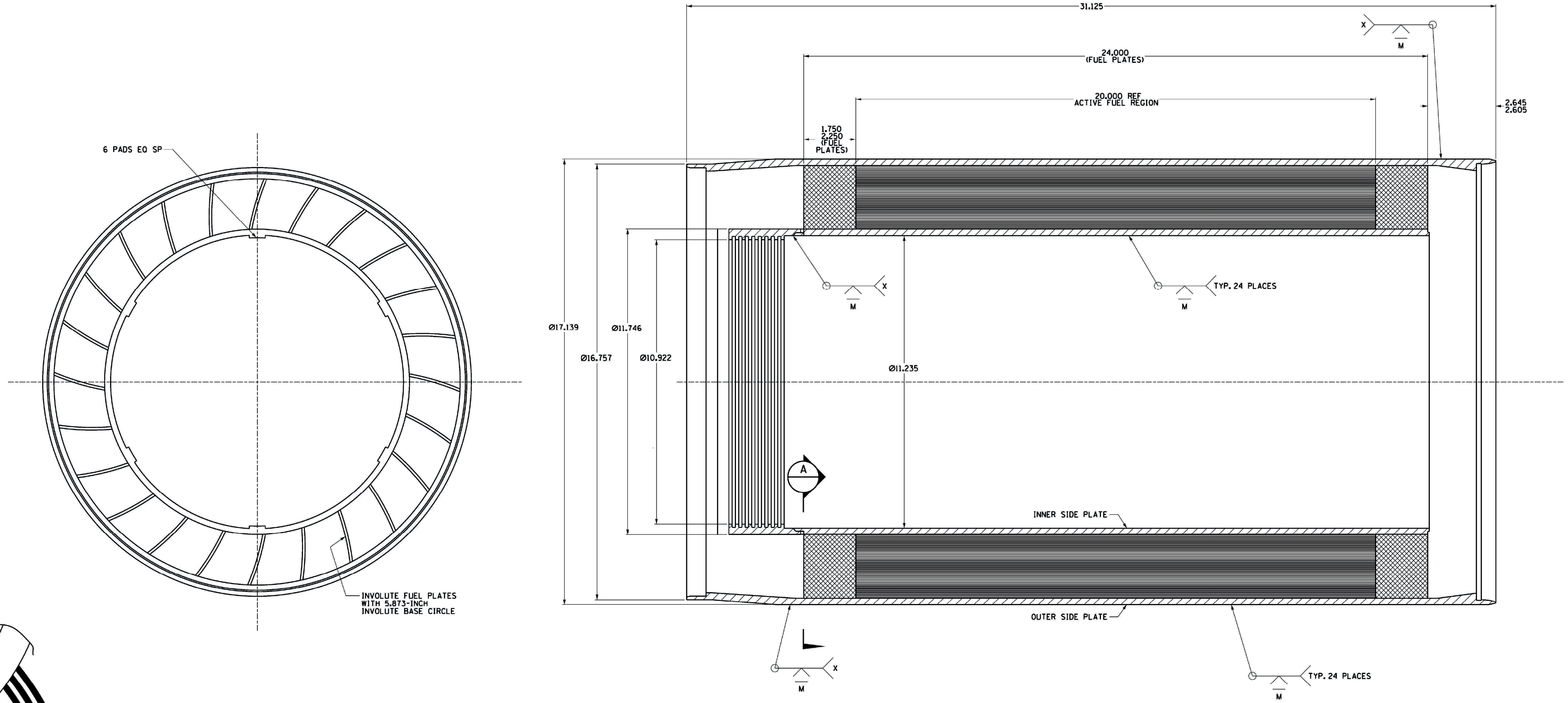
MICROSTATION DRAWING

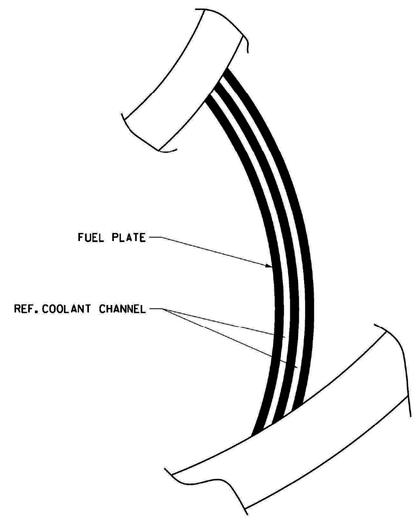
Drawing Attached

Fig. 1.8. HFIR Fuel Unirradiated Outer Element Certification Drawing—M-11524-OH-107 (Rev. 4).

GENERAL NOTES:

1. FUEL ELEMENT NOMINAL WEIGHT IS 205 Lb.
2. FUEL ELEMENT U-235 CONTENT IS 6738g. MIN./6871g. MAX.
3. ALL DIMENSIONS ARE ±.005 UNLESS OTHERWISE NOTED.
4. MATERIAL OF CONSTRUCTION:
   INNER AND OUTER SIDE PLATES - AL 6061
   FUEL PLATE
   CORE: U_3O_8 (ENRICHMENT 92-94%) + AL POWDER (CERMET)
   CLADDING: AL 6061
5. MINIMUM FINISHED MACHINED SIDE PLATE THICKNESS IS:
   INNER SIDE PLATE - 0.108 INCHES
   OUTER SIDE PLATE - 0.128 INCHES
6. COOLANT CHANNEL THICKNESS (DISTANCE BETWEEN FUEL PLATES) IS 0.050 ± 0.010 INCHES
7. BOTH THE FUEL PLATES ATTACHMENT WELDS AND ADAPTOR WELDS ARE FULL PENETRATION JOINTS COMPLETED BY AUTOMATED GAS METAL ARC WELDING PROCESS. WELDS ARE SUBSEQUENTLY MACHINED ALONG WITH ELEMENT TO OBTAIN FEATURES NOTED ON THIS DRAWING.
8. ADAPTOR WELDS ARE INSPECTED BEFORE FINAL MACHINING BY RADIOGRAPHY. BOTH FUEL PLATE ATTACHMENT WELDS AND ADAPTOR WELDS ARE VISUALLY INSPECTED AFTER FINAL MACHINING.
9. THE MINIMUM AVERAGE CLADDING THICKNESS IS 0.010-INCHES.





SECTION A-A

NOT FOR FABRICATION

LICENSING RESTRICTIONS APPLY

REVISION CERTIFIED FOR CONSTRUCTION AUG 26 2020

REFERENCE DRAWINGS	NUMBER
HFIR OUTER FUEL ELEMENT ASSEMBLY	E-42126
HFIR FUEL UNIRRADIATED INNER ELEMENT CERTIFICATION DRAWING	M-11524-OH-106
SHIPPING CONTAINER FOR UNIRRADIATED OUTER HFIR ELEMENT ASSEMBLY	M-20978-EL-002

CAUTION NUCLEAR EQUIPMENT:
ANY PROCESS OR MATERIAL (INCLUDING PACKAGING AND SHIPPING MATERIALS) THAT HAS THE POSSIBILITY OF LEAVING A RESIDUE CONTAINING ANY OF THE HALIDE ELEMENTS (PRIMARILY CHLORINE AND FLUORINE), METALLIC ELEMENTS (PRIMARILY COPPER, LEAD, NICKEL, SILVER, THORIUM, AND TIN) OR CARBON/GRAPHITE ON THE SURFACE OF ANY HFIR COMPONENT AFTER FINAL CLEANING SHALL NOT BE USED. MERCURY IN ANY FORM SHALL BE SPECIFICALLY PRECLUDED IN THE PROCUREMENT OF ALUMINUM RAW MATERIALS AND IN ALL PROCESSING AND MANUFACTURING OPERATIONS.

GENERAL SPECIFICATIONS
UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
REMOVE BURRS/BREAK EDGES
FRACTIONS ± N/A
xx DECIMALS ± N/A
xxx DECIMALS ± N/A
ANGLES ± N/A
FILLETS N/A MAX.
MACHINE FINISH N/A √ MAX.
SCALE: NONE

NO.	REVISIONS	DESIGNER / TASK LDR	REVIEWER / SAFETY	Q.A.S. / C.C. MGR	APPROVED / MAINT MGR	OPS. MGR / DATE
4	SEE DCN 13590	CED/TJ / DLP	CPK / WBK	N/A / KBN	N/A / N/A	N/A / 8-26-20
0	SEE DCN 13433					

DESIGNER	DATE	SAFETY ANALYST	DATE	APPROVED	DATE
T.W. Evans/TAJ	2-28-20	N/A	-	N/A	-
TASK LEADER	DATE	Q.A. SPECIALIST	DATE	MAINT MGR	DATE
D. L. Pinkston	2-28-20	N/A	-	N/A	-
DESIGN REVIEWER	DATE	CFG. CONTROL MGR	DATE	OPERATIONS MGR	DATE
C. P. Kilgore	2-28-20	K. B. Napier	3-2-2020	N/A	-

OAK RIDGE National Laboratory — HIGH FLUX ISOTOPE REACTOR
Managed by UT-Battelle for the US Department of Energy
RESEARCH REACTORS DIVISION

FACILITY H.F.I.R. BLDG. NO. 7900

HFIR FUEL UNIRRADIATED OUTER ELEMENT CERTIFICATION DRAWING

M-11524-OH-107 E REV. 4

AS DESIGNED

MICROSTATION DRAWING

Deleted

Deleted

Deleted

Deleted

Deleted

Deleted

Deleted

Deleted

1.4 References

1. Code of Federal Regulations, Title 10, Part 71, "Transport of Licensed Materials," January 1991
2. Safety Requirements for the Packaging and Transportation of Hazardous Materials, Hazardous Substance and Hazardous Waste, DOE Order 5480.3, September 5, 1987
3. ORNL/ENG/TM-9, Safety Analysis Report for Packaging: The ORNL HFIR Unirradiated Fuel Element Shipping Container, November 1977
4. Letter to J.A. Lenhard from R. W. Montross dated September 28, 1988. Subject: DOE Certificate of Compliance (#5797) License Renewal Request for HFIR Unirradiated Fuel Shipping Containers
5. Nuclear Regulatory Commission, Proposed Revision 2 to Regulatory Guide 7.9, Standard Format and Content of Part 71 Applications for Approval of Packaging for Radioactive Material, May 1986.
6. Deleted.
7. USA/9099/B(U)F (NRC), ATR Fuel Element Shipping Container Safety Analysis, EGG-ATR0-7737 (Rev. 1), August 19, 1987

specified in 10 CFR 71.71 there should be no loss or dispersal of radioactive contents, no significant increase in external radiation levels, and no substantial reduction in the effectiveness of the packaging.

For hypothetical accident conditions, the applicable criteria are given in 10 CFR 71.51(a) (2); namely, that under the loading conditions specified in 10 CFR 71.73 there should be no escape of radioactive material exceeding an A2 quantity in one week and no external radiation dose rate exceeding 1 rem per hour at 1 m from the external surface of the package. These criteria are satisfied if the fuel element does not melt or fracture into numerous small pieces.

The design criteria are based on the importance of a particular structural component to the performance of the total packaging under both normal and hypothetical conditions of transport. As stated previously, the fuel element is the critical component. The fuel element is composed of fuel plates (which contain the fuel) and side plates. (Refer to Chapter 1, Figs. 1.7, 1.8, and 1.11.) The side plates provide a cylindrical shell for the fuel plate assembly and extend a minimum of approximately 2.5 in. past the fuel plates on either end of the fuel element assembly. The composition of the fuel plates is such that 2 in. of solid aluminum is provided on either end of the fuel plate.

The fuel element is designed to meet the containment requirements for both the normal and hypothetical accident conditions as stated in 10 CFR 71.51 (a) (1 and 2). The analysis in Chapter 3 shows that the fuel element can be subjected to the regulatory fire, without the container, and still maintain the acceptable A2 release values. Chapter 4 discusses containment boundaries for the fuel element. The primary containment boundary is defined as the cladding bonded to the fuel matrix of the HFIR fuel plates.

Each end of the fuel element has a minimum of approximately 4.5 in. of solid aluminum that could be deformed without affecting the containment of the fuel. Because small deformation on the ends of the side plates would not adversely affect the integrity of the fuel plate, the stress on the side plates can exceed the yield stress of the aluminum. However, the stress in the fuel plate should be below or approximately at the yield stress. Local yielding of the fuel plates is acceptable provided the overall geometry changes in the fuel element do not affect the criticality calculations. Local yielding is allowable because testing has been performed on irradiated fuel plates that shows the plates capable of bending in excess of 80 degrees without cracks being formed in the plate. However, local bending of fuel plates shall be limited to less than 20 degrees, which provides a factor of safety greater than 4.

Additional criteria for other components of the fuel element container are as follows:

1. The lid should remain secured to the body of the container during normal transport conditions.

2. For normal conditions, the maximum stress in the bolts shall be less than the allowable stress of the bolt material (23 ksi).

3. During hypothetical accident conditions, the lid must remain in place on the body of the container.

4. The plywood within the unirradiated fuel element shipping container serves as an impact absorber to minimize adverse effects on the fuel element during transport. Therefore, deformation of the plywood can occur during hypothetical accident conditions.

The functional design criteria for the container and the fuel elements are identified in Tables 2.0 and 2.0a.

2.2 Weights and Centers of Gravity

The inner element of the HFIR fuel assembly weighs 103.5 lb; the outer element weighs 205 lb. The inner container model weighs 660 lb when loaded; the outer container model weighs 1050 lb when loaded. The container lids of the inner and outer models weigh 90 and 134 lb, respectively. The center of gravity of the package is approximately at the geometric center.

2.3 Mechanical Properties of Materials

The material mechanical properties that were used in the structural evaluation are listed in Table 2.1. The primary load-bearing material is the carbon steel shell and top and bottom plates that form the drum-shaped containment. The shell is reinforced with four carbon steel angles, and the bottom is supported on a skid structure composed of carbon steel channels and plates. Within the container, Douglas fir exterior grade (finished both sides) plywood provides thermal insulation and energy-absorption capability. A 1-inch-thick layer of polyethylene foam that lines the inside of the cavity provides additional energy-absorption capability. The structural portions (nonfueled region) of the fuel elements, excluding the cladding that forms the primary containment of the radioactive material, are constructed of alloy 6061-T6 aluminum.

The mechanical properties used in the calculations performed for this update to the original SARP[4] were taken to be the same as those used in the original calculations, provided that the values were traceable to an authoritative standard or appeared to be reasonable with existing data. The hot-rolled carbon steel sheet used for the drum and lid plate having a carbon content of approximately 0.1% is most likely AISI 1010. The yield strength of this material typically ranges from 30,000 to 40,000 psi, so use of a value of 30,000 psi is reasonable. The steel angles, channels, and plates are most likely ASTM A36 having a yield strength of 36,000 psi, so use of a yield strength of 30,000 psi for this material is also reasonable.

The material properties given in Table 2.1 for plywood are based on in-plane data. That is, tests were performed with loads applied in the

This section makes reference to the results of tests performed on plutonium nitrate shipping containers that were reported[14] in the June 1965 *Proceedings of the International Symposium for the Packaging and Transportation of Radioactive Materials*. Puncture tests were made on these plutonium containers during which the containers were dropped 40 in. onto a 6-in.-diameter steel bar. The resulting damage was minimal; no ruptures occurred.

A comparison of the HFIR inner and outer packages with the plutonium nitrate packages is given in Table 2.3. The packages are similar in that both the HFIR and plutonium nitrate packages make use of low-carbon steel drums as the outer container and use wood as the thermal insulator. The payload weights of the packages differ significantly. The 3-1iter plutonium nitrate payload weighs approximately 10% of the HFIR inner fuel assembly; the 10-1iter plutonium nitrate payload weighs approximately 15% of the HFIR outer fuel assembly. The container is shown in Fig. 2.4.

The lid closures on the two types of packages are also significantly different. The bolt-type locking ring used to secure the covers of the plutonium nitrate packages is less secure than the bolted closure design of the HFIR packages. Failure of the single locking ring bolt under direct impact could allow the cover to slip off under load.

With regard to the potential puncture of the packaging as a result of a 40-in. drop onto a 6-in.-diameter steel bar, local stiffness of the packaging is most important. The thickness and stiffness (modulus of elasticity and crush strength) of the wood are approximately the same for both types of packages. However, the thickness of the carbon steel shell and top and bottom plates of the plutonium nitrate packages is one-half the thickness of that of the HFIR packages. Hence, the plutonium nitrate packages are more likely to be punctured during such a test. Because no ruptures occurred and damage resulting from the test was minimal, it was concluded that the puncture test would produce minimal damage of the HFIR packages.

2.7.3 Thermal

Calculations were prepared for the melting of inner and outer HFIR fuel elements in a 1475° F (800° C) fire for the case in which the element is completely removed from the shipping cask and directly exposed to the fire. Based on the conservative evaluation presented in Appendix B to Chapter 3, it was shown that less than an A_2 amount of radioactive material will be released if the assembly is exposed to the regulatory fire for 30 minutes. Based on these results, which are in compliance with the regulations, the structural integrity of the fuel container is not essential to meeting the thermal requirements of the regulation.

Table 2.3 Comparison of Packages

	HFIR		Plutonium Nitrate	
Container	Inner	Outer	3-Liter	10-Liter
Height (in.)	45	45 3/4	34 3/4	~ 69 1/2
Diameter (in.)	25	31 1/2	22 1/2	22 1/2
Thickness (in.)	0.119 (11 gage)	0.119 (11 gage)	0.06 (16 gage)	0.06 (16 gage)
Material	Low-Carbon Steel (~0.1% C)	Low-Carbon Steel (~0.1% C)	Low-Carbon Steel	Low-Carbon Steel
Cavity				
Height (in.)	30 1/4	31 1/8	~ 20	~ 55
Diameter (in.)	10 7/8	17 3/8	~ 4 3/4	~ 4 3/4
Thermal Insulation				
Shell Thickness (in.)	6	6	~ 8 3/4	~ 8 3/4
Top Thickness (in.)	6	6	~ 5 1/2	~ 5 1/2
Bottom Thickness (in.)	6	6	~ 5 1/2	~ 5 1/2
Material	Douglas Fir Plywood	Douglas Fir Plywood	Laminated Oak	Laminated Oak
Shock Absorber				
Shell Thickness (in.)	1	1	N/A	N/A
Top Thickness (in.)	1	1	N/A	N/A
Bottom Thickness (in.)	1	1	N/A	N/A
Material	Polyethylene Foam	Polyethylene Foam	N/A	N/A
Package Configuration	See Fig. 1.2 of the SARP	See Fig. 1.1 of the SARP	See Fig. 2.4 of the SARP	Same as 3-Liter only twice as high
Closure	Sixteen 3/8-in. steel bolts	Sixteen 3/8-in. steel bolts	12-gage bolt-type locking ring	12-gage bolt-type locking ring

2.9 Fuel Elements

The HFIR fuel element cladding and fuel matrix as described in Chapter 4, Containment, provide for the containment of radioactive material under normal or accident test conditions. The entire fuel assembly is made up of two fuel elements, each element consisting of an annular array of fuel plates. The annuli are identified as the inner and outer fuel elements. The inner element contains 171 identical fuel plates, and the outer element contains 369 identical plates that differ slightly from those in the inner element.

The fuel plates are formed into an involute configuration to provide maximum fuel volume with a graded fuel distribution, a uniform metal-to-water ratio, and a high heat transfer surface-to-core volume ratio, while maintaining a constant channel spacing.

The fuel elements are assembled by inserting formed fuel plates into slots in two concentric cylindrical side plates. The fuel plates are attached to the side plates by welds deposited in circumferential grooves. End adapters are welded to each end of the fuel assembly to provide location and support of the fuel assembly within the reactor.

The cladding and fuel matrix provide sufficient mechanical integrity to establish the containment integrity of the radioactive material contained within the unirradiated HFIR fuel elements.

The salient features of the fuel element and side plates are provided in Figs. 1.7 and 1.8.

4. Containment

This chapter identifies and discusses the package containment for the normal conditions of transport and the hypothetical accident conditions.

4.1 Containment Boundary

The radioactive contents of research reactor fuel elements that are typically classified as Materials Testing Reactor (MTR)-type fuel (such as HFIR) are contained in a fuel matrix and clad in aluminum providing a containment boundary. Together the fuel matrix and cladding provide a boundary that withstands the combined effects of the structural and thermal tests for normal and hypothetical accident conditions when transported in the HFIR unirradiated fuel element container. The aluminum cladding bonded to the fuel matrix and the fuel matrix itself provides the primary boundary or containment. This type of bonded containment would limit any failure to the immediate area of the bond because each section of the containment or cladding is independent of the remaining boundary.

Several studies[1,2] have been conducted at the Oak Ridge National Laboratory to evaluate the release of fission products from irradiated aluminide fuel at high temperature. A summary of these studies is given in Table 4.1, and two are presented in Appendices A and B. The general conclusion is that irradiated MTR-type fuel plates maintained at less than 932°F (500°C) will release no fission products. For comparison purposes, characteristics of irradiated HFIR Fuel are listed in Table 4.2. Unirradiated fuel cladding and the fuel matrix have a higher level of containment integrity than irradiated fuel. Therefore, any boundary parameter selected for irradiated fuel will be conservative when applied to unirradiated fuel. To ensure a sufficient safety margin in the spent fuel analysis, 752°F (400°C) was considered the maximum temperature to which irradiated MTR fuel plates may be subjected before the release of fission products from the fuel matrix would be evident.

HFIR fuel elements are plate-type fuel elements, which are characterized by fuel meat plates consisting of U_3O_8 fuel particles. Several fuel plates are assembled with aluminum alloy hardware to make up a fuel assembly. Plate-type fuel assemblies are illustrated in Figures 1.7, 1.8, and 4.1.

Fuel meat plates are fabricated by powder metallurgy methods. Fuel plates are clad with 6061 aluminum alloy. A metallurgical bond between the fuel meat matrix and the cladding is formed by hot rolling during the fabrication process. This fabrication method produces a fuel plate with isolated fuel fines ranging in size from 100 to 325 mesh (44 µm to 150 µm) evenly dispersed throughout a metal matrix that has

Table 4.1. Summary of Clad Integrity Test

Type of fuel	General description	Irradiation parameter	Clad integrity temperature limit
1. UAL_x Ref. 1, Plate #5	40% ^{235}U cladding 6061-Al Plate thickness: 0.051 to 0.061 in Av clad thickness 0.009 to 0.011 in. Density: 1.94 to 2.3 g/cm^3	60% burnup	500°C (blister formation at 500°C)
2. U_3O_8 Plate # a. 0-50-1 b. 0-58-8	20% ^{235}U cladding 6061-Al Plate thickness: 0.050 to 0.060 in Av clad thickness 0.015 to 0.017 in. Density: 2.8 to 3.1 g/cm^3	60% burnup	500°C (500°C blister formation)
3. U_3Si Plate #A-19	20% ^{235}U cladding 6061-Al Plate thickness: 0.50 in Av clad thickness 0.016 in. Density: 4.8 g/cm^3	60% burnup	475°C (500°C blister formation)

Note : Reference 4 contains fabrication information for miniature fuel plates for the Reduced Enrichment Research and Test Reactor (RERTR) program

Table 4.2 Characteristics of Irradiated HFIR Fuel

Fuel Type	Loading (g)	Composition	Density	Burnup (MWd)	Burnup (%)	Clad thickness (in)
HFIR	9400	U_3O_8-Al	0.52 g or 0.64 g/cm^3 ^{235}U	2200	30	0.010

4.1.1 Containment Boundary

The containment boundary is the fuel matrix and cladding of the HFIR fuel plates. The clad material is 6061 aluminum or equivalent. The average clad thickness is a minimum of 0.010 in. Figure 4.1 shows a HFIR fuel plate cross section.

4.1.2 Containment Penetrations

There are no penetrations into the cladding.

4.1.3 Seals and Welds

Cladding for HFIR fuel is bonded to the fuel matrix by a hot rolling technique. As referenced in Sect. 4.1, the container seal or gasket is part of the container boundary and is not part of the containment.

HFIR fuel plates are welded to the inner and outer side plates of both the inner and outer fuel elements. The fuel elements are designed such that these welds do not penetrate through the aluminum cladding that forms a frame around the cermet fuel boundary. Fuel located at the surface of the plates is not allowable during reactor operation because fission products will contaminate the reactor coolant.

4.1.4 Closure

Initial cladding integrity is verified by ultrasonic inspection and a blister test (nonbond indication) at 932°F (500°C) for every fuel plate at HFIR. All HFIR fuel plates are program annealed at high temperature, followed by a controlled cooldown rate.

The controlling parameters or verification tests to ensure appropriate integrity is maintained for the fuel plates, and fuel elements are verified through appropriate sampling to ensure that the integrity of the containment for these components is maintained. The following verification processes are maintained for fuel plates that serve as the containment boundary for this container:

Item	Verification Process	Frequency per Plate
1	Plate inspections	100%
2	Core outline	100%
3	Blister inspection	100%
4	Ultrasonic inspection	100%
5	Destructive test to verify clad thickness and bond quality	See Note

Note: Sample size and frequency are based on trending data of minimum clad thickness.

During the fuel plate fabrication process, a representative number of plates from different fuel plate lot numbers are destructively tested. Therefore, item 5 represents a minimum for maintaining confidence in an established fabrication process. Because inspections or tests performed per items 1 through 4 are completed on 100% of the fuel plates used in the assembly of fuel elements, the results of these tests demonstrate the adequacy of containment. Thus, the containment boundary of each plate shipped has been verified, and the cladding-to-cladding bond and cladding-to-fuel bond have been shown to be acceptable. Item 5 is an overview test that provides physical performance data on the adequacy of the other tests (items 1 through 4).

The fabrication and inspection process for HFIR unirradiated fuel elements includes special requirements to establish the containment conditions for unirradiated fuel. The destructive and nondestructive tests (items 3, 4, and 5) provide assurance that the cladding bond strength to the Al-cermet fuel is sufficient to provide the containment boundary for the solid non-dispersible radioactive content. .

4.2 Requirements for Normal Conditions of Transport

4.2.1 Containment of Radioactive Material

The HFIR fuel plates can be considered the containment boundary when maintained in the environment provided by the HFIR unirradiated fuel element container. The secondary boundary formed by the cask cavity and lid ensures that no damage to the fuel occurs during normal conditions of transport. The HFIR unirradiated fuel element container has been used in over 200 fuel shipments for HFIR since 1965 with no release of radioactive material.

4.5 Appendices

A. *Release of Fission Products from Irradiated Aluminide Fuel at High Temperature*, T. Shibata, K. Kanda, K. Mishima, T. Tamai, M. Hayshi (Japan), J. L. Snelgrove, D. Stahl, J. Matos, A. Travell (ANL-USA), and F. N. Case and J. C. Posey (ORNL-USA), ANL/RERTR/TM-4, Conf. 821155.

B. *Release of Fission Products from Miniature Fuel Plates at Elevated Temperature*, John C. Posey, ANL/RERTR/TM-4, Conf. 821155.

C. Deleted

D. Irradiation Testing of Miniature Fuel Plates for the RERTR Program, R. L. Senn and M. M. Martin, ORNL/TM-7761 (July 1981)

APPENDIX C

(Chapter 4)

Deleted